

**INVESTIGATING THE ABILITY OF AUTOMATED LICENSE  
PLATE RECOGNITION CAMERA SYSTEMS TO MEASURE  
TRAVEL TIMES IN WORK ZONES**

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## LIST OF ABBREVIATIONS

GDOT	Georgia Department of Transportation
ALPR	Automated License Plate Recognition
MPH	Mobile Plate Hunter
IRA	Irish Republican Army
CCTV	Closed-Circuit Television
URA	Undergraduate Research Assistant
GRA	Graduate Research Assistant
HOT	High Occupancy Toll
HTML	Hypertext Markup Language
OCR	Optical Character Recognition

## SUMMARY

This thesis evaluates the performance of a vehicle detection technology, Automated License Plate Recognition (ALPR) camera systems, with regards to its ability to produce real-time travel time information in active work zones. A literature review was conducted to investigate the ALPR technology as well as to identify other research that has been conducted using ALPR systems to collect travel time information. Next, the ALPR technology was tested in a series of field deployments in both an arterial and a freeway environment. The goal of the arterial field deployment was to evaluate the optimal ALPR camera angles that produce the highest license plate detection rates and accuracy percentages.

Next, a series of freeway deployments were conducted on corridors of I-285 in Atlanta, Georgia in order to evaluate the ALPR system in active work zone environments. During the series of I-285 freeway deployments, ALPR data was collected in conjunction with data from Bluetooth and radar technologies, as well as from high definition video cameras. The data collected during the I-285 deployments was analyzed to determine the ALPR vehicle detection rates. Additionally, a script was written to match the ALPR reads across two data collection stations to determine the ALPR travel times through the corridors. The ALPR travel time data was compared with the travel time data produced by the Bluetooth and video cameras with a particular focus on identifying travel time biases associated with each given technology. Finally, based on the knowledge gained, recommendations for larger-scale ALPR work zone deployments as well as suggestions for future research are provided.

# **CHAPTER 1**

## **INTRODUCTION**

### *1.1 Problem Statement*

Traffic congestion caused by work zones has been a constant cause of motorist angst. Efficient delivery of work zone travel time information to motorists via variable message signs or cell phone alerts can influence travelers to change their travel plans or take alternate routes. Providing information to drivers will help reduce motorist angst, reduce traffic congestion in work zones, and improve mobility in work zones. This thesis comes from work produced for the Georgia Department of Transportation's (GDOT) Work Zone Technology Testbed project. The goal of the Work Zone Technology Testbed project is to evaluate possible turnkey vehicle detection systems that can be deployed in non-permanent platforms to track and communicate accurate travel times in operational work zone corridors.

### *1.2 Objective*

The goal of the Work Zone Technology Testbed project is to set up a physical work zone test bed for the deployment and testing of various vehicle detection, vehicle monitoring, and data communication systems. These technologies will be evaluated in terms of the accuracy of the data gathered, the robustness of the system, the ease of system deployment, the deployment costs, and the equipment limitations. One of the vehicle detection systems selected for testing is the ELSAG North America Automatic License Plate Recognition (ALPR) system, which is the focus of this thesis. Through a literature review and the analysis of data collected during various field deployments, this

thesis will present the background and workings of ALPR systems as a whole, a summary of the capabilities of the ELSAG ALPR system in particular, and an analysis of the feasibility of using the ELSAG ALPR system as a means of collecting real-time travel time data in work zones.

### *1.3 Equipment*

The primary equipment types used in the work zone study include the ELSAG ALPR system, Panasonic high definition video cameras, Digiwest Bluetooth units, and Georgia Tech Custom Bluetooth units. These equipment types are introduced and described in the sections below.

#### **1.3.1 ELSAG ALPR**

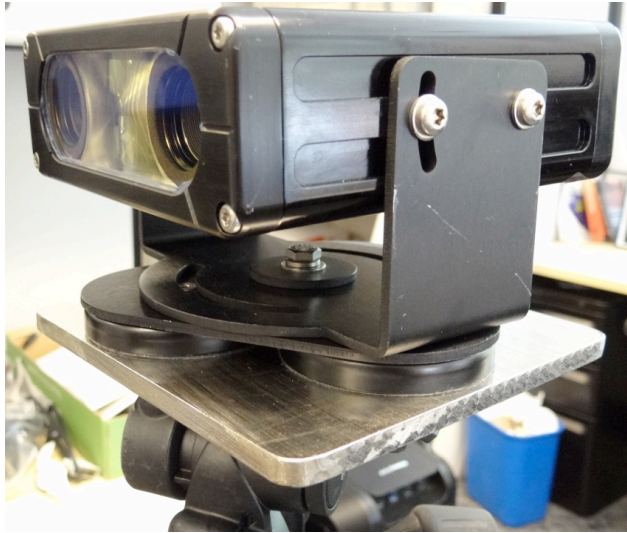
The ELSAG North America (ELSAG) company specializes in law enforcement systems. The ELSAG Mobile Plate Hunter-900 (MPH-900) offers fixed ALPR systems that can be permanently mounted to structures such as bridges or overpasses as well as mobile ALPR systems that can be mounted on police vehicles. The ELSAG website states that the MPH-900 (Mobile Plate Hunter – 900) is used by hundreds of law enforcement agencies across all fifty states in the United States. ELSAG states that the MPH-900 ALPR system can read up to 1,800 plates per minute and has an accuracy rate of 99% [1].

In the greater Atlanta area specifically, both the Alpharetta and the Sandy Springs police departments have one ELSAG license-plate reader each, which they use to patrol the GA-400 corridor. ELSAG ALPR systems are also used by police departments in Atlanta, Gwinnett County, DeKalb County, and by the Georgia Highway Patrol. For

research purposes for the work zone technology testbed project, Georgia Tech purchased two ELSAG mobile MPH-900 systems from the vendor TJ Madden & Associates that each consist of one processing unit, three cameras (25mm, 35mm, and 50mm focal lengths), three camera connection cables, and one voltage converting power cable at a cost of \$20,000 per system (ELSAG North America, 2012).

#### 1.3.1.1 ALPR Equipment Modifications

Because ELSAG's primary clients are law enforcement agencies, their ALPR camera systems are typically powered by police vehicles. To work around this issue, the Georgia Tech research group purchased four large 12 volt gel cell batteries to power the equipment during field deployments. Also, because ELSAG typically sells ALPR camera systems to law enforcement agencies, the cameras come equipped with three circular magnets attached to their bases so that they can be mounted on the trunk of police vehicles. For field deployment purposes, square metal plates capable of screwing into the tops of tripods were created and the magnetic bottoms of the cameras were mounted to those magnetic plates so that they could be deployed in the field using tripods as shown in Figure 1 below.



**Figure 1: Photo of the configuration used to mount the ALPR cameras to tripods**

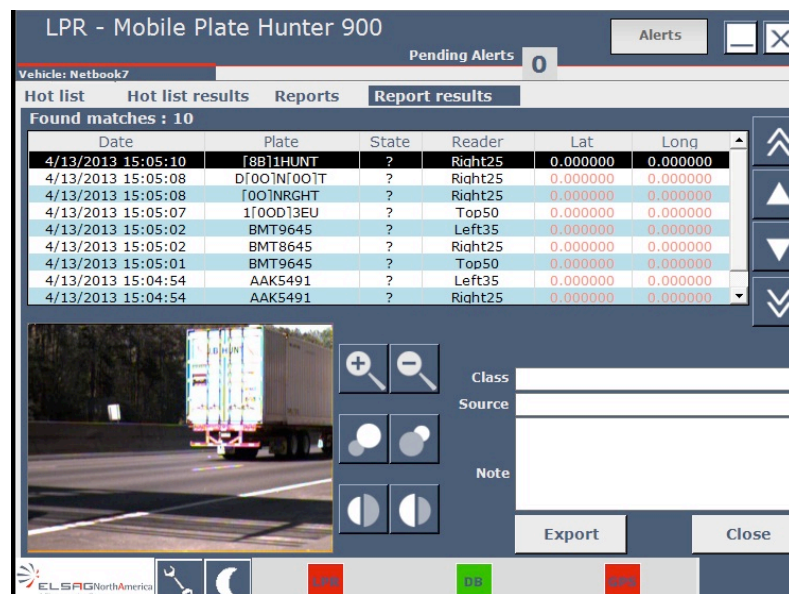
#### 1.3.1.2 ALPR Car System ® Program

The ELSAG ALPR system includes a computer program called Car System ® that acts as the user interface for the ALPR system, which needs to be installed on a computer that is connected to the ALPR processing unit during data collection. The main function of the Car System ® program is to display and record the captured license plate and vehicle information in real time. For each captured license plate, the program records the date and time stamp of capture, the camera of capture, the recorded license plate number, a black and white image of the license plate including the back of the vehicle, and a zoomed-in infrared image of only the license plate. When each license plate is captured, the program can be set to produce a beeping sound, will momentarily display the infrared license plate image, and will add the license plate information to the running display of the captured license plate information. A screen shot showing the display of the Car System ® program during the data collection process is shown in

Figure 2 below. In addition to displaying the data, the program also stores an archive of past ALPR data and allows the user to export the data collected during specified time periods as an HTML (Hypertext Markup Language) file. A screen shot showing the data export interface within the Car System ® program is shown in Figure 3 below.



**Figure 2: The data collection screen within the Car System ® program**



**Figure 3: The data export screen within the Car System ® program**



The Car System ® program also has a mode that allows the user to check and adjust the view of each camera that is connected to the system. When the program is in this mode, the user can select a specific camera and the display will show the camera's view allowing the user to adjust the positioning of the camera until the view is set to the desired area. This feature is useful to the research team when establishing the deployment setup in order to ensure that a camera's view of vehicle license plates is not obstructed in any way. The Car System ® program also allows users to label each of the cameras in a manner that corresponds to which port on the processing unit the camera is connected to via the camera connection cable. The research team chose to label the cameras as "Right25", "Left35", and "Top50" corresponding to the focal length of each camera and to the port on the processing unit to which each camera connects.

#### 1.3.1.3 ALPR Set-up

During field deployments, each ALPR camera system is set up so that each of the three cameras is connected to the correct port on the processing unit via the camera connection cables. Each of three tripods is mounted with a metal plate that screws into the top and then each camera is mounted onto a tripod by placing the magnetic bottom of the camera onto the metal plate. The tripods are raised to a height of approximately three feet in order to simulate the height of the back of a police car and are sometimes raised slightly higher if required due to the presence of nearby obstructive objects such as guardrails or concrete barriers. Then a level tool is utilized to adjust the tripods via their adjustment levers in order to ensure that each camera is level. Next, the camera to vehicle angles are adjusted in one of two manners depending on the deployment: For the first deployment, the camera angles are created by pointing the camera view at a focal

point in the roadway that is determined by measuring the two legs of the angle triangle. For the second set of deployments, the camera angles are established by utilizing the angle-measuring tool on the tripods to position the camera views at predetermined angles. First, the cameras are pointed parallel to the roadway so that they are facing towards the back of passing vehicles and so that the tripod angles are positioned at zero degrees. Then the cameras are turned towards the roadway at the predetermined angle as will be shown later in Figures 7 and 8. At this point the netbook is connected to the processing unit and the camera view mode of the Car System ® program is utilized for each camera to check the camera view and make sure it is not obstructed. Finally, one end of the voltage converting cable is connected to the two terminals of the gel cell battery and the other end is connected to the processing unit.

### **1.3.2 High Definition Video Cameras**

High definition video cameras are utilized in both of the deployment series presented in this thesis as a method of obtaining comparative vehicle travel time data. The brand of high definition video cameras used is the Panasonic 700X series. These cameras are mounted on tripods and are stationed on either sidewalks or freeway overpasses adjacent to the vehicle travel way. These cameras are positioned so that they are facing the back end of passing vehicles in order to capture the license plate information.

### **1.3.3 Digiwest Bluetooth**

The performance and capabilities of commercial Bluetooth vehicle detection units produced by the company Digiwest were also investigated in parallel with the testing of

the ELSAG ALPR units. The Digiwest units are not the focus of this thesis but their deployment is mentioned in the I-285 freeway work zone deployment procedures and the travel times produced from their vehicle detection data are compared with the travel times produced from the ALPR collected data and the other vehicle detection equipments.

#### **1.3.4 Georgia Tech Custom Bluetooth**

Georgia Tech custom Bluetooth units are also deployed in concert with the ELSAG ALPR system and the Digiwest Bluetooth units during the I-285 freeway work zone deployments and the travel times produced by these units are also compared with the travel times produced by the ALPR systems. As with the Digiwest Bluetooth units, these Bluetooth units are also not the focus of this thesis. However, Stephanie Zinner has authored a companion thesis produced in fall 2012 where more information about the performance of these units can be found [2].

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### *2.1 ALPR Technology Background*

The first available record of license plate recognition for travel time studies was presented at the Vehicle Navigation and Information Systems Conference in 1991. Research was conducted at the University of Tokyo over a two year period to develop an algorithm to estimate or predict travel time and compare the results to travel times measured by license plate readers [3]. There is no mention of the automation of these readers in this conference paper, but it does summarize the successful measure of travel time using license plate recognition devices.

From July 1993 through February 1997 the city of London developed the first large scale real-time automated license plate recognition technology as a counter-terrorist effort against ongoing city bombings by the Irish Republican Army (IRA) [4]. The system was developed by retrofitting advanced closed-circuit television (CCTV) units and installing them at all seven entrance points to the Square Mile extents of London, also known as the “ring of steel”. The development came about through a combined effort of the public and private sectors. By February 1997, the license plate monitoring units were recording plates of passing vehicles continuously for 24-hour days, and through a link with the police database were able to process plates and provide feedback to system operators within four seconds.

Over the years, ALPR technology applications to law enforcement have grown, including placement at intersections in the form of red-light cameras and installation on police cruisers for mobile tracking of flagged vehicle plates [5]. The scope of ALPR technology has continued to expand in recent years to the area of traffic management, which features roadside camera mounting for travel-time, speed, volume, and origin-destination studies [6]; [7]; [8].

## *2.2 How ALPR Technology Works*

The first major phase in automatic license plate recognition is to locate a license plate from which to capture an image. This phase works by using typical license plate features to identify potential license plate candidates. These features can be separated into features associated with the format of a license plate and features associated with the characters of a license plate. Format features include: shape, symmetry, height-to-width ratio, color, texture of grayness, spatial frequency, and variance of intensity values. Character features include: line, blob, the sign transition of gradient magnitudes, the aspect ratio of characters, the distribution of intervals between characters, and the alignment of characters [9].

The next major phase in automatic license plate recognition is to capture an image and extract a vehicle's license plate information from that image. The process that pulls the license plate number from an image is composed of four steps: image acquisition, license plate extraction, license plate segmentation, and character recognition. A flow chart representing this process with example images is shown in Figure 4 below. The image acquisition stage involves acquiring an image of a vehicle using a camera. Camera parameters such as the type of camera, the resolution, the shutter speed, the orientation,

and light all have an effect on the quality of the image produced. The second step in the process involves extracting the license plate portion of the image from the entirety of the image. This step works by identifying features such as plate boundary, plate color, or plate texture (the color change between the characters and the background) and processing only the pixels that have those features. The third step in the process is to segment the isolated license plate in order to extract the characters for the recognition step. This step also involves correcting any issues with the extracted plate image such as tilt or non-uniform brightness. The segmentation process is achieved using features such as pixel connectivity, projection profiles, prior knowledge of characters, character contours, or a combination of these features. The last step in the process is character recognition, which outputs the license plate number. Techniques in this step include comparing the raw data to templates and comparing extracted features to pre-stored features [10].



**Figure 4: Steps associated with extracting a license plate number from an image (Du, 2011)**

### *2.3 ALPR Travel Time Studies*

In one study by Christine Buisson et al. ALPR units were deployed on a heavily congested 50km corridor in the French Alps in order to provide travel time information to motorists through variable message signs. The study highlighted that ALPR units were chosen over the currently installed inductive loops because the ALPR units allow the direct measurement of travel times while the inductive loops infer travel times indirectly from spot speed estimates. The study discussed that measuring the travel times in smaller subsections of the total length of the corridor allows the system to be more reactive to sudden changes in congestion conditions. Therefore, the main goal of the study was to investigate the optimal number of ALPR units to deploy in the corridor to accurately

capture the congestion and travel time conditions while also being cost effective. Seven possible deployment locations were identified based on selection criteria and a model was developed to estimate the optimal number and positioning of the ALPR devices in the corridor [11].

In another study by Guixiang Liu et al., an algorithm was developed to produce travel time information from ALPR systems in real-time. This study also highlighted that ALPR systems can produce more accurate travel times than technologies that must infer travel times from speed data because the ALPR systems provide a direct measurement of travel times. The study also mentions that because the license plate recognition technology is mature, the ALPR systems are able to recognize about 90 percent of passing vehicles, which ensures that an effective number of samples will be captured. The travel time algorithm uses an event-driven mechanism to process the data in real-time. The algorithm also contains processes that handle exceptions such as screening abnormal data and correcting and compensating for missing data and processes that smooth the data to reduce data fluctuation. The algorithm was evaluated in field tests using manual sampling data and calculation data to validate the solution. The fitting degree between the artificial sampling travel time data and the travel time data from the algorithm was about 86 percent before the correction and smoothing processes and about 91 percent after these processes [12].



## **CHAPTER 3**

### **DESIGN OF EXPERIMENT**

#### *3.1 Introduction*

As a part of measuring the capabilities of the ELSAG ALPR system to produce real-time travel time information in work zones the system's accuracy and detection rate performance were investigated through a series of deployments in two different environments: an arterial setting for one day and a freeway setting for six days. The primary goal of the arterial data collection deployment was to investigate the camera angles that produce the best license plate detection rate and accuracy using the angles recommended to the research team by the ELSAG vendor, TJ Madden & Associates, as a starting point. The main goals of the freeway data collection deployments were to investigate the license plate detection rate and accuracy capabilities of the ALPR camera system in a freeway environment and to investigate the performance of the systems as a method of producing real-time travel time information in work zone environments.

#### *3.2 Camera Angle Configuration Test*

##### **3.2.1 Objective**

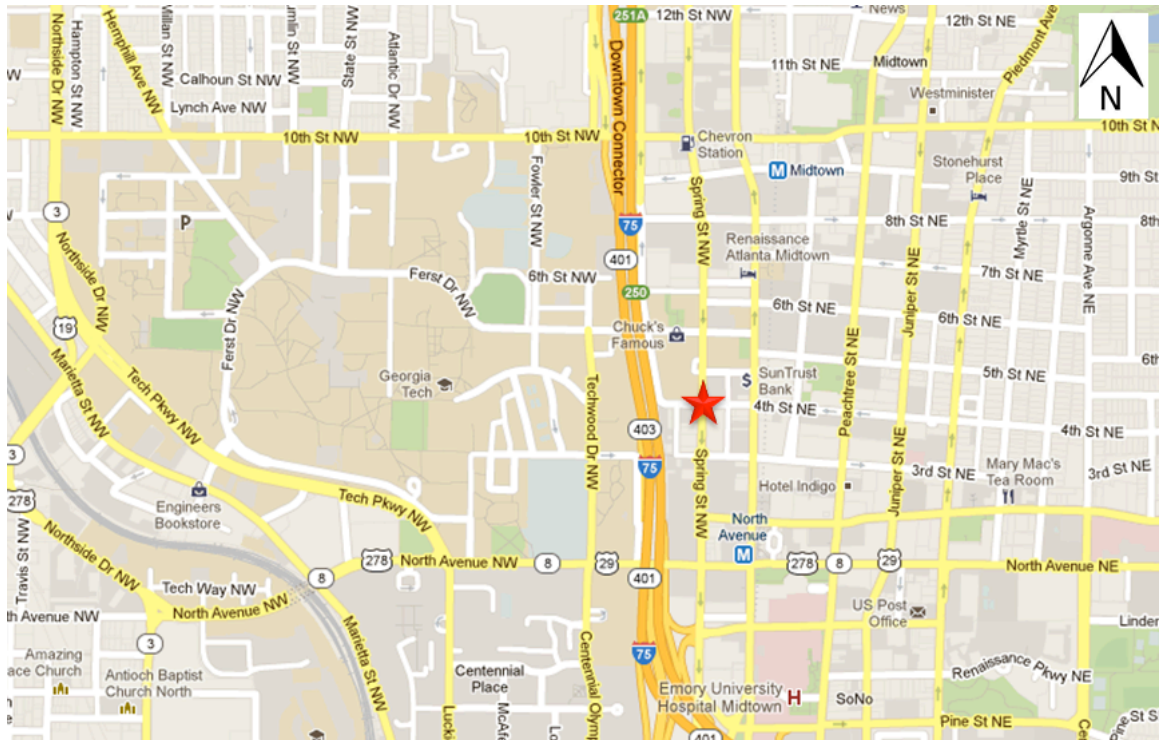
The objective of the camera angle configuration test was to investigate the optimal camera angle for each of the three ALPR cameras that produces the highest license plate detection rate and the highest license plate accuracy percentage across the associated travel lanes. The focal length of each ALPR camera makes that camera specially designed to perform better for specific distances. Because of its long focal length, the 50mm camera is best suited for capturing the license plates of vehicles

traveling in the lanes farthest from where the camera is located. Because of its short focal length, the 25mm camera is best suited for capturing the license plates of vehicles traveling in the lanes closest to where the camera is located. Because the 35mm camera has a medium sized focal length, it is best suited for capturing vehicles traveling in the middle lanes of the roadway.

The ELSAG vendor, TJ Madden & Associates provided the Georgia Tech research team with instructions on how they typically configure cameras mounted on the trunk of a police car in order to obtain the greatest detection rate and accuracy percentages. As a starting point for the initial tests of the performance of the ELSAG ALPR camera systems, the research team recreated these recommended camera angle configurations (shown later in Figures 7 and 8). The recommended camera configurations were reproduced by setting up the cameras at a similar height to the trunk of a police car (three feet), at a similar distance from the edge of the travel lanes as a police vehicle would be, and at the same angles to the roadway as were recommended.

### **3.2.2 Site Selection**

The site chosen for this deployment was the arterial corridor of Spring Street between 4<sup>th</sup> Street and 3<sup>rd</sup> Street in Midtown Atlanta, Georgia. The Spring Street corridor was chosen because it is a one-way street with four lanes, which allowed for the cameras' performance to be measured out to four lanes without the interference of another direction of traffic and without the heavy traffic associated with a freeway. This site location was also chosen based on its close proximity to the Georgia Tech campus. Figure 5 below shows the Spring Street deployment location.



**Figure 5: Map showing the site location of the camera angle configuration test in Midtown Atlanta as denoted by the red star (Google Maps, 2013)**

### 3.2.3 Deployment Procedure

The camera angle configuration test along the Spring Street corridor took place on August 15<sup>th</sup>, 2012. The official start of the data collection period was 12:19 PM and the official end time was 2:03 PM. Prior to deployment, a deployment plan detailing the data collection and safety procedures for the deployment was created and a notification call was made to the Atlanta and Georgia Tech Police Departments notifying them of the location of the deployment and of the equipment and personnel that would be located there.

In this deployment, only one complete ALPR system was deployed because data was only collected at one location. The three ALPR cameras (25mm, 35mm, and 50mm

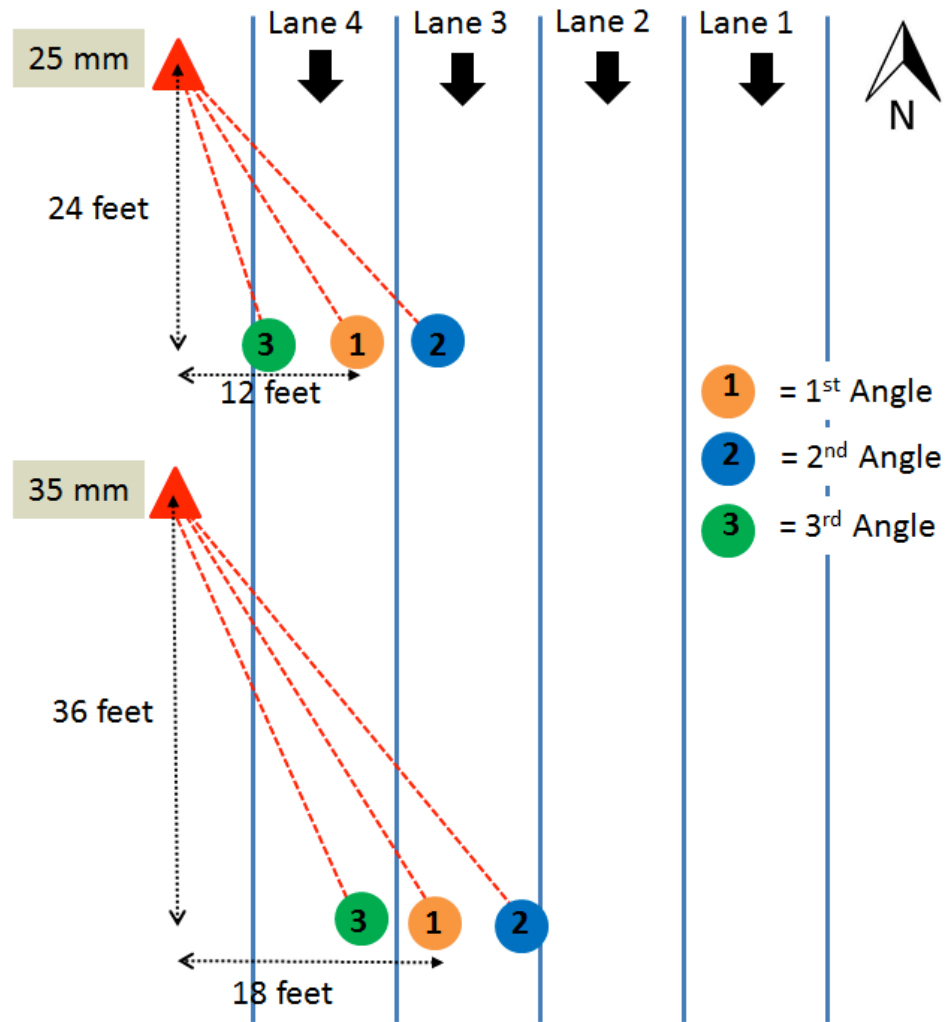
focal lengths) were set up in a row along the back of the sidewalk adjacent to the Spring Street corridor. The cameras were set up at the back of the sidewalk at a distance of five feet from the edge of the roadway, so as not to interfere with pedestrian travel along the sidewalk. Each of the tripod-mounted cameras was set up at a height of three feet above the ground to simulate the height of the back of a police vehicle. Figure 6 below shows the position of the ALPR cameras along the sidewalk.



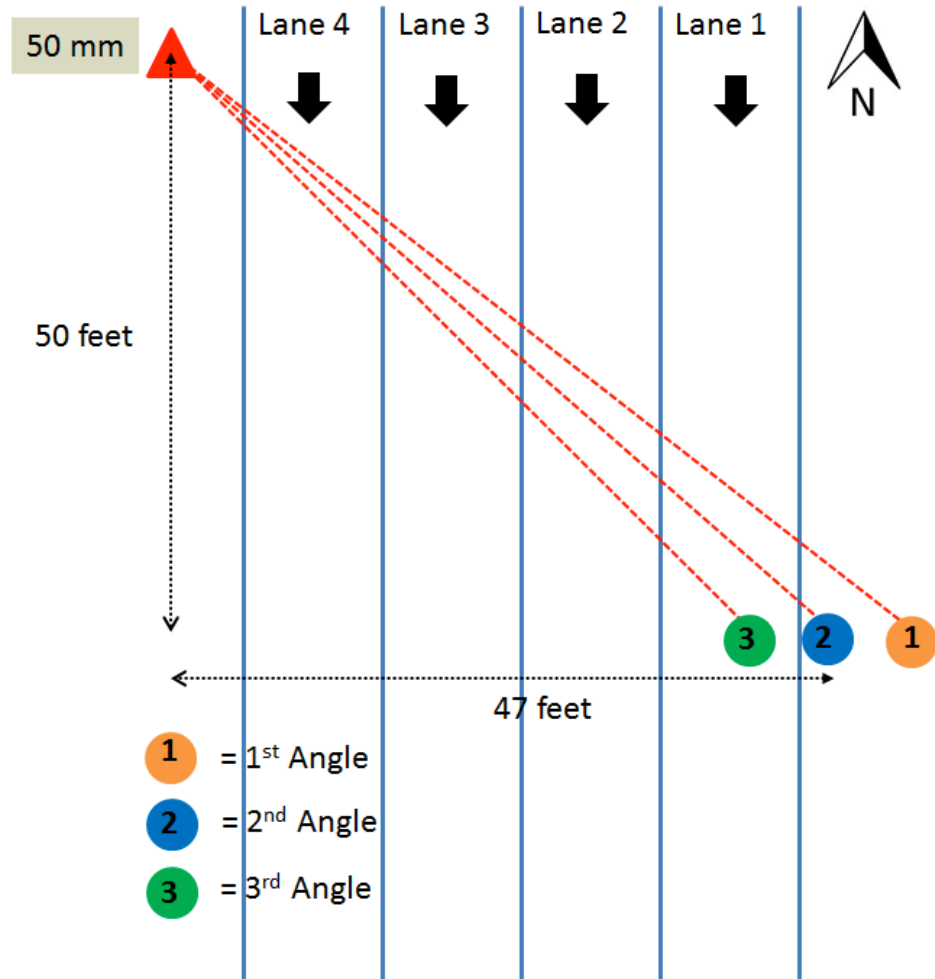
**Figure 6: ALPR camera set up along the Spring Street corridor (facing south)**

During this deployment, ALPR data was collected for a total of 90 minutes during which each of the three cameras was tested at three different angles for 30 minutes each. The first camera angle was tested from 12:19 PM – 12:49 PM, the second from 12:56 PM – 1:26 PM, and the third from 1:33 PM – 2:03 PM. The gaps of time between each of the testing periods correspond to the time it took to adjust the camera angles.

For the first 30 minutes of the deployment each of the three cameras was set up at the recommended angle to the roadway as was indicated by TJ Madden & Associates. For the second 30 minutes each of the three cameras was rotated outward so that they were focused at a spot six feet closer to the opposite edge of the roadway than during the first 30 minutes. For the final 30 minutes each of the three cameras were rotated inward so that they were focused at a spot six feet farther from the opposite edge of the roadway than during the first 30 minutes. These camera angles were set up by establishing the corresponding point of focus by measuring the necessary distance parallel to the road and the necessary distance perpendicular to the road and then aiming the camera at the space above that point of focus. The distances parallel to the road were measured using a rolling measuring tape and the distances perpendicular to the road were estimated using lane widths as a guide. Graphics of the three set-up angles for each of the three cameras are shown in Figures 7 and 8 below.



**Figure 7: Schematic of the three camera angles tested for the 25mm and 35mm cameras during the camera angle configuration test**



**Figure 8: Schematic of the three camera angles tested for the 50mm camera during the camera angle configuration test**

### 3.2.4 Comparative Video Data

During the camera angle configuration test a high definition video camera was placed on either side of the Spring Street corridor in order to collect video license plate data for comparison with the ALPR data. The video data collected during the Spring Street deployment was manually processed to by watching the video and recording the license plate number of each passing vehicle and its lane of travel. Each of these cameras was mounted onto a tripod and set up at the back portion of the sidewalks in order to

minimize interference with pedestrian traffic. The cameras were positioned so that they were facing the back end of passing vehicles in order to record the vehicle license plates. The locations of these two high definition video cameras are shown in Figure 9 where the green triangles represent the high definition video cameras and the red triangles represent the ALPR cameras.

The processed video data was used to provide a means for assigning vehicles detected by the ALPR cameras to their lane of travel, for obtaining an overall traffic count for detection rate calculations, and for establishing the correct license plate numbers necessary for accuracy assessments. Facing in the direction of vehicle travel (south), the lanes on Spring Street were numbered from left to right starting with lane one and ending with lane four. The camera located on the left side of the corridor was positioned to record the vehicles traveling in lanes one through three and the camera located on the right side of the corridor was positioned to record the vehicles traveling in lanes two through four. This resulted in the vehicles in lanes numbered two and three being captured in both videos. The processed data for these two lanes were combined, which increased the accuracy of the data because, in some instances, vehicles were blocked from one camera's view due to occlusion by other vehicles but were visible in the second camera's view.





**Figure 9: Overview of the deployment set-up showing the locations of the high definition cameras and the ALPR cameras**

### *3.3 I-285 Freeway Deployments*

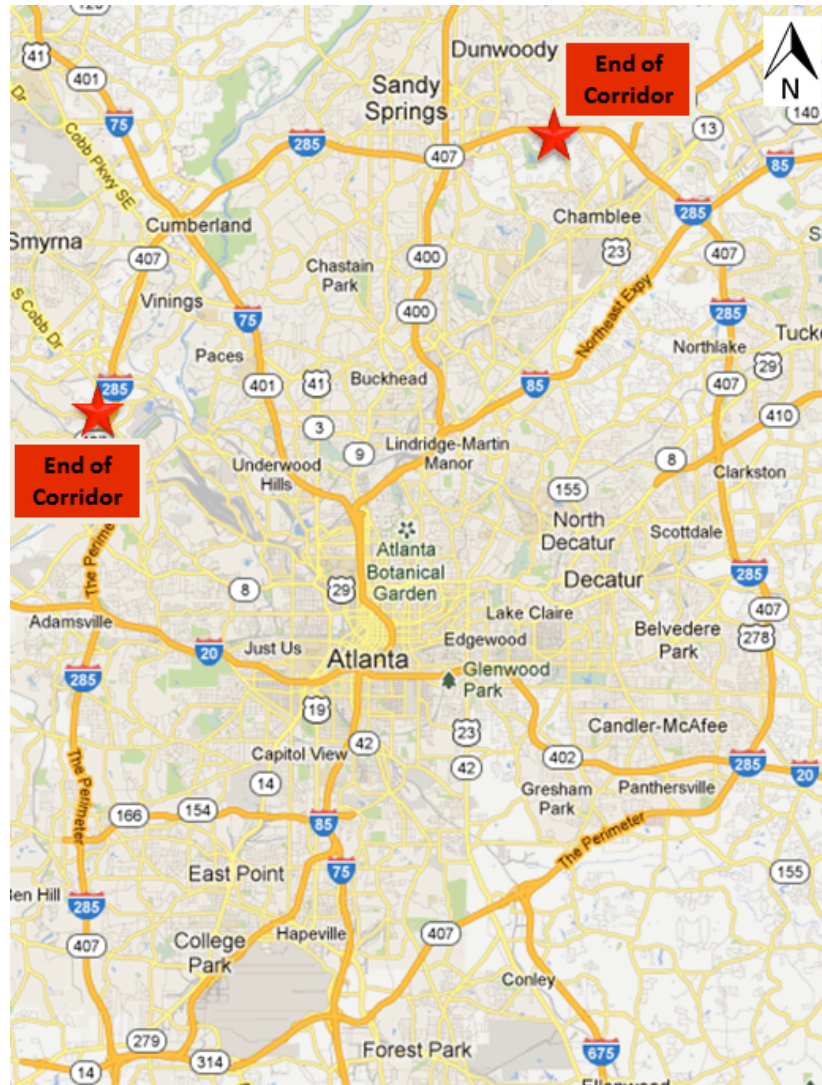
#### **3.3.1 Objective**

The objectives of the freeway work zone deployments were to test the detection rate and accuracy performance of the ALPR camera system in a freeway work zone environment and to measure the capability of the system to produce real-time travel time information through work zone corridors. Comparative high definition video footage, Bluetooth data, and radar data were collected simultaneously with the ALPR data so that comparisons between the travel times produced by the different technologies could be made and an investigation of any potential travel time biases could be conducted. Another reason for collecting comparative high definition video footage was to provide

an overall vehicle count through the corridor for detection rate analyses. An additional objective of the freeway work zone deployments was to further the investigation of the optimal camera angle as the camera angle has shown to have a significant influence on both license plate detection rate and accuracy performance.

### **3.3.2 Site Selection**

The northwest portion of Interstate-285 in Atlanta, Georgia between South Cobb Drive to Chamblee Dunwoody Road was selected as the testing corridor for the freeway data collection deployments due to the on-going GDOT paving and improvement project scheduled to occur in this area during the fall of 2012 and the spring of 2013. The location of this corridor of I-285 relative to the City of Atlanta is shown in Figure 10 below. Construction is scheduled to take place only on weekends and requires partial lane closures. However, during weekdays all travel lanes are scheduled to be open. Weekend only construction allowed the research group to schedule several non-work zone deployments on weekdays and several active work zone deployments on weekends. Weekday deployments took place on Friday, September 7<sup>th</sup>, 2012, Wednesday, September 12<sup>th</sup>, 2012, and Friday, September 14<sup>th</sup>, 2012. Active work zone deployments took place on Saturday, September 29<sup>th</sup>, 2012, Saturday, October 20<sup>th</sup>, 2012, and Saturday, November 10<sup>th</sup>, 2012.



**Figure 10: Map showing the location of the I-285 deployment corridor in relation to the City of Atlanta (Google Maps, 2013)**

### 3.3.2.1 Site Selection Criteria

Because the exact construction locations are not determined until a few days before the construction is to begin each weekend, all interchanges along this portion of the I-285 corridor were investigated as potential deployment locations for the freeway work zone deployments. Several factors were considered when evaluating the suitability of the eastbound and westbound sides of each interchange as a potential deployment

location. Many of the constraints had to do with the accessibility and the configuration of the interchange freeway roadside. The roadside had to be able to be accessed safely via sidewalks and crosswalks from a nearby parking area. The roadside also had to contain minimal shrubbery or trees so that the personnel and equipment could travel down to the side of the freeway. The roadsides were also required to have either a guardrail or concrete wall separating the freeway traffic from the roadside so that the personnel and equipment could be protected from the vehicles travelling along the freeway. Finally, the ground behind the guardrail or concrete wall in the roadside had to be close to level so that the tripods for the custom Bluetooth and the Digiwest Bluetooth could be properly set up without the risk of them falling over due to unlevel ground.

Another major constraint on the selection of deployment locations was that they had to have a freeway overpass with sidewalks adjacent to the side of the bridge, which could provide the location for the video license plate footage to be collected. Additionally, when selecting two or more deployment locations to be used for collecting travel time information it was helpful to select locations that did not have a major interchange, such as I-75 or GA-400, between them as a large percentage of vehicles would exit to these freeways, significantly reducing the number of matches for travel time calculations.

Finally, other additional constraints on deployment location selection were associated with specific conditions related to the Bluetooth data collection. Sites were selected that were expected to have minimal interference with the Bluetooth communication from surrounding objects or devices. Roadsides next to the freeway exit ramp were optimal because even if exiting vehicles were detected, it was not likely that

they would be reentering the freeway and therefore would not introduce significant error into the travel time calculation. Additional information on the site selection constraints associated with the Bluetooth devices can be found in Stephanie Zinner's companion thesis (Fall 2012) [2].

Many of these deployment constraints are specific to this research project. As the research team was not part of the construction team it did not have access to work vehicles that could pull off of the freeway at any location to set up equipment. In future work zone deployments where the contractor is placing the equipment, much more flexibility in site location would be possible.

#### 3.3.2.2 Site Identification for the I-285 Freeway Deployments

In the 10-mile corridor of I-285 from Paces Ferry Road to Ashford Dunwoody Road, four suitable site locations were identified on Eastbound I-285 and two on Westbound I-285 as suitable deployment locations for the I-285 freeway deployments. The Eastbound sites were the Paces Ferry Road, Northside Drive, Roswell Road, and Chamblee Dunwoody Road interchanges and the westbound sites were the Riverside Drive and Northside Drive interchanges. Figure 11 below shows the suitable site locations along this corridor of I-285 with the endpoints of the corridor labeled with red boxes, the eastbound sites labeled with green boxes, the westbound sites labeled with blue boxes, and the two intermediate freeway interchanges labeled with orange boxes. Table 1 below also shows a summary of the date, day of week, start time, end time, site locations, and work zone status for the I-285 freeway deployments. More specific detail about each of the six I-285 deployments is presented later in sections 3.3.3.4.1 – 3.3.3.4.6.



**Figure 11: Overview of the site locations for the six deployments along the I-285 corridor (Google Maps, 2013)**

**Table 1: Summary of the date, day of week, start time, end time, site locations, and work zone status for the six I-285 freeway deployments**

Date	Day of Week	Start Time	End Time	Site A	Site B	Site C	Work Zone/ Non-work zone
09-07-12	Friday	8:25 AM	10:25 AM	EB Paces Ferry Road	EB Northside Drive	N/A	Non-work zone
09-12-12	Wednesday	7:40 AM	9:40 AM	EB Northside Drive	EB Roswell Road	N/A	Non-work zone
09-14-12	Friday	7:35 AM	9:40 AM	EB Paces Ferry Road	EB Northside Drive	EB Roswell Road	Non-work zone
09-29-12	Saturday	7:40 AM	10:50 AM	WB Riverside Drive	WB Paces Ferry Road	N/A	Non-work zone
10-20-12	Saturday	9:52 AM	12:32 PM	EB Paces Ferry Road	EB Northside Drive	N/A	Work zone
11-10-12	Saturday	8:40 AM	10:50 AM	EB Roswell Road	EB Chamblee Dunwoody Road	N/A	Non-work zone

In the eastbound direction, the distance between Paces Ferry Road and Northside Drive is approximately 4.3 miles, the distance between Northside Drive and Roswell Road is approximately 3.3 miles, and the distance between Roswell Road and Chamblee

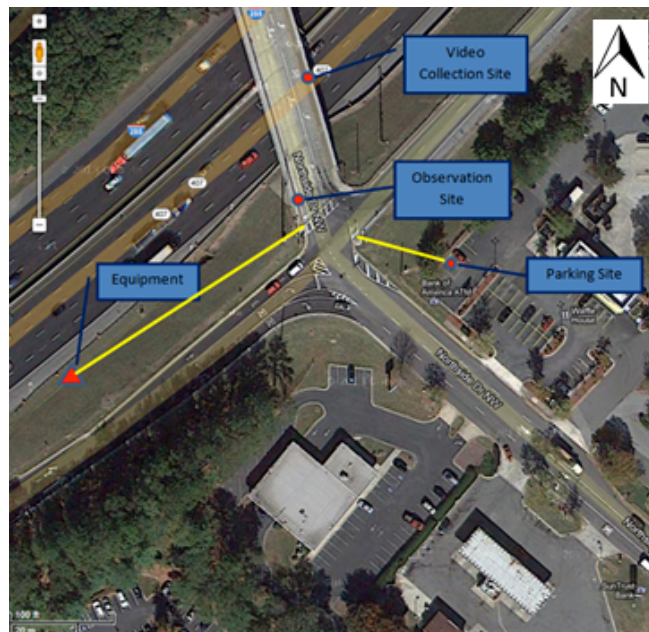
Dunwoody Road is approximately 3.8 miles. In the westbound direction the distance between Riverside Drive and Paces Ferry Road is approximately 5.9 miles. The major interchange with I-75 is located between the Paces Ferry Road and Northside Drive sites for the eastbound direction and between the Riverside Drive and Northside drive sites for the westbound direction. Additionally, the major interchange with GA-400 is located between the Roswell Road and Chamblee Dunwoody Road sites for the eastbound direction.

Figures 12 – 17 below show aerial views of each of the first six suitable I-285 deployment locations and have indications of the equipment location, video camera location, and personnel observation location. The equipment location indicates the placement of the ALPR camera system, the custom Bluetooth, and the Digiwest Bluetooth. The video camera location indicates the placement of the high definition video cameras on the overpass, and the personnel observation location indicates where the personnel sat to observe the ALPR and Bluetooth equipment during the course of the deployment. The approximate distance between the equipment location and the overpass at is 175 feet at Eastbound Paces Ferry Road, 175 feet at Eastbound Northside Drive, 150 feet at Eastbound Roswell Road, 175 feet at Eastbound Chamblee Dunwoody Road, 150 feet at Westbound Riverside Drive, and 75 feet at Westbound Northside Drive.





**Figure 12: Site set-up at eastbound Paces Ferry Road (Google Maps, 2013)**



**Figure 13: Site set-up at eastbound Northside Drive (Google Maps, 2013)**



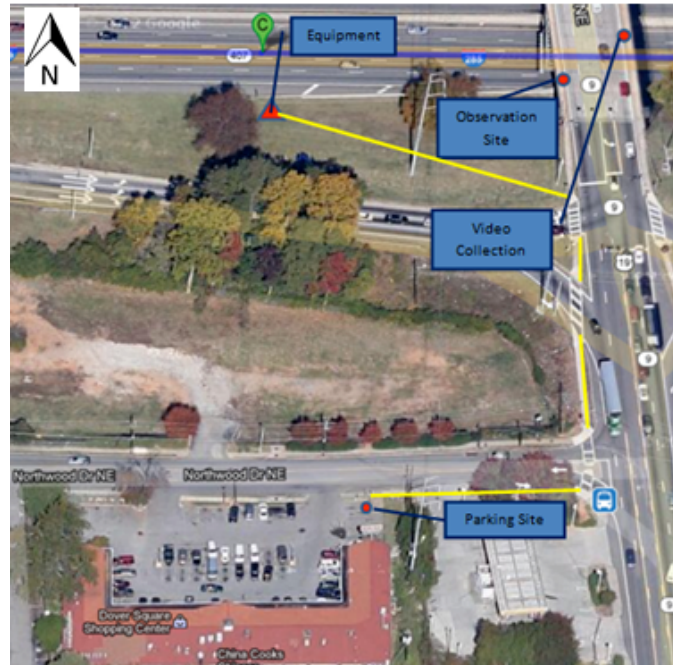


Figure 14: Site set-up at eastbound Roswell Road (Google Maps, 2013)

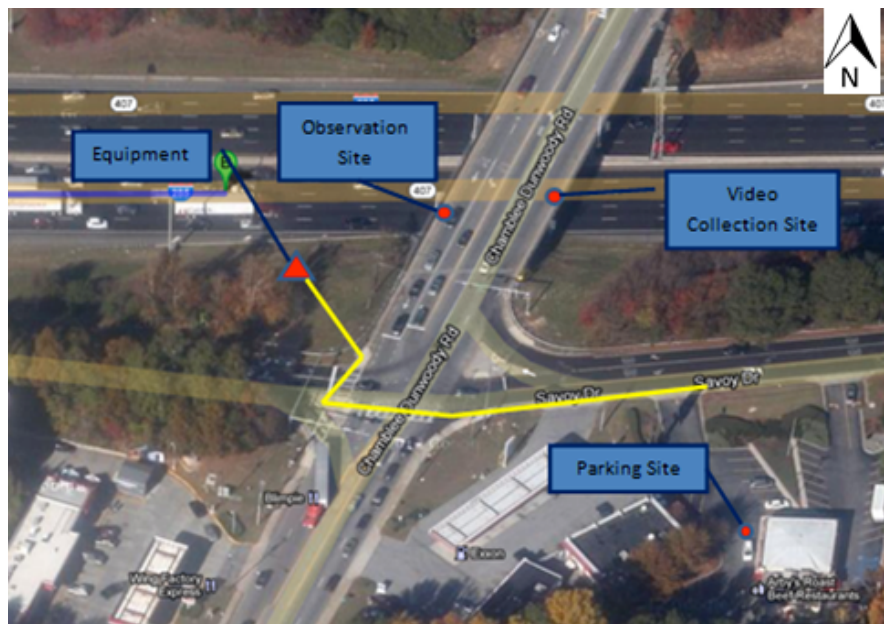


Figure 15: Site set-up at eastbound Chamblee Dunwoody Road (Google Maps, 2013)

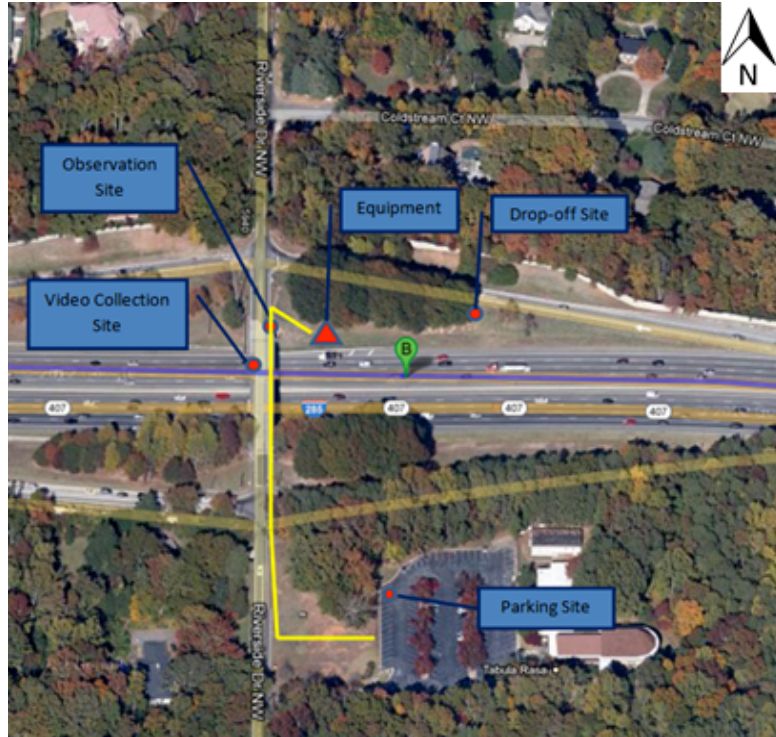


Figure 16: Site set-up at westbound Riverside Drive (Google Maps, 2013)

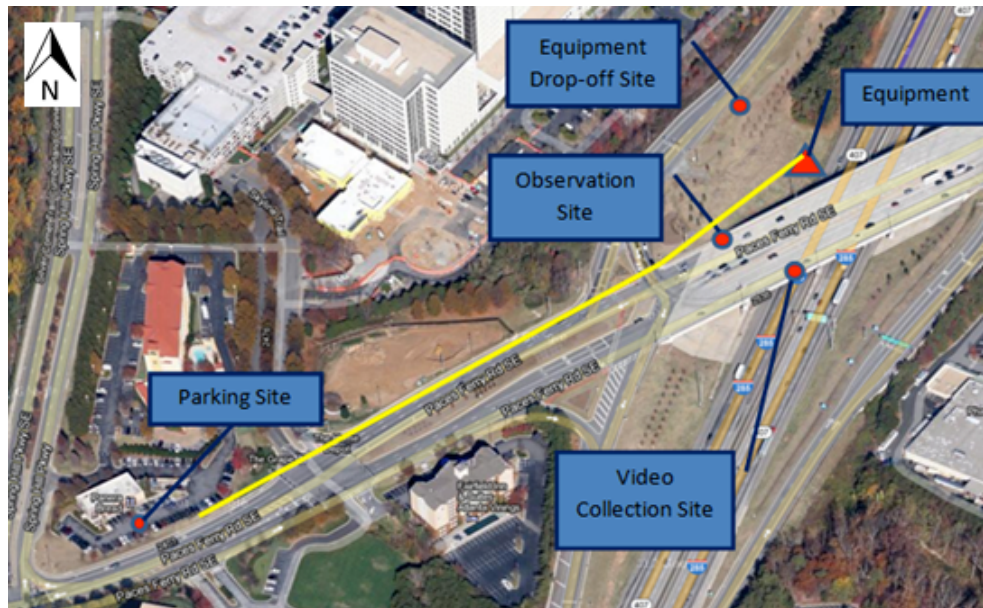


Figure 17: Site set-up at westbound Paces Ferry Road (Google Maps, 2013)

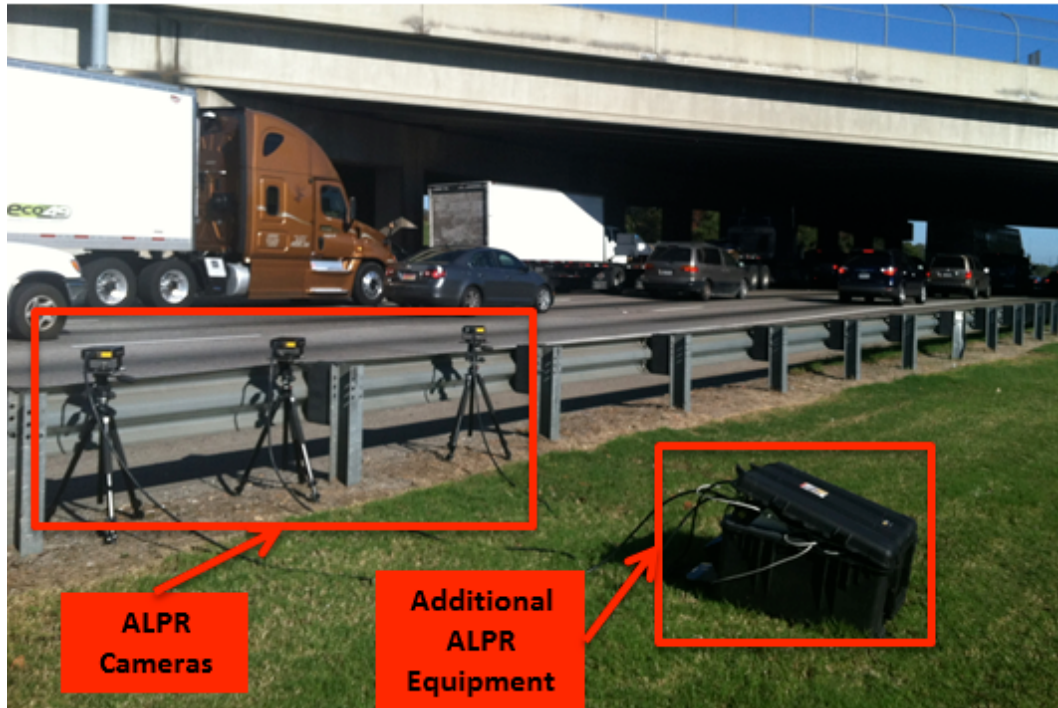
### **3.3.3 Deployment Procedure**

Before each field deployment the research team prepared a deployment data collection plan, which was provided to GDOT. Additionally, the local police were contacted in each county of the deployment to inform them of the location, duration, and equipment involved in the data collection effort.

#### **3.3.3.1 ALPR System Set-up**

For each of the six days of deployment, one complete ALPR camera system was set up at each site consisting of three cameras (25mm, 35mm, and 50mm), one processing unit, three tripods, one netbook, one battery, and various connection cables. The three cameras mounted to the tripods were positioned adjacent to the guardrail or concrete barrier separating the freeway from the roadside. The desired camera height was about three feet to simulate the height of the back of a police car, but in most instances the cameras had to be slightly raised in height so that they had a clear view of the vehicles above the top of the guardrail or concrete barrier. Figure 18 below shows an example from Paces Ferry Road of the ALPR camera system set up for the I-285 freeway deployments.

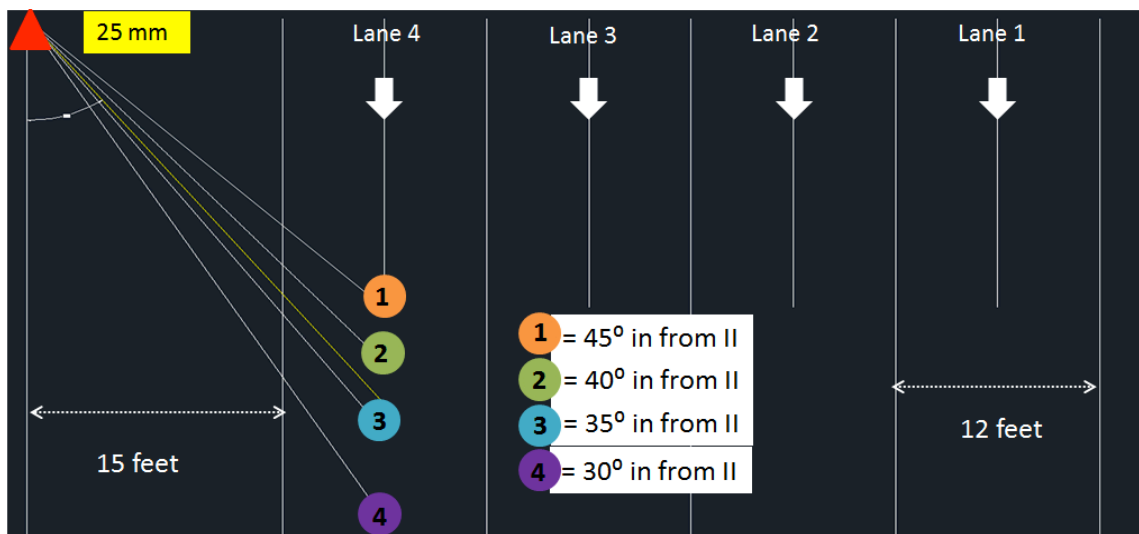




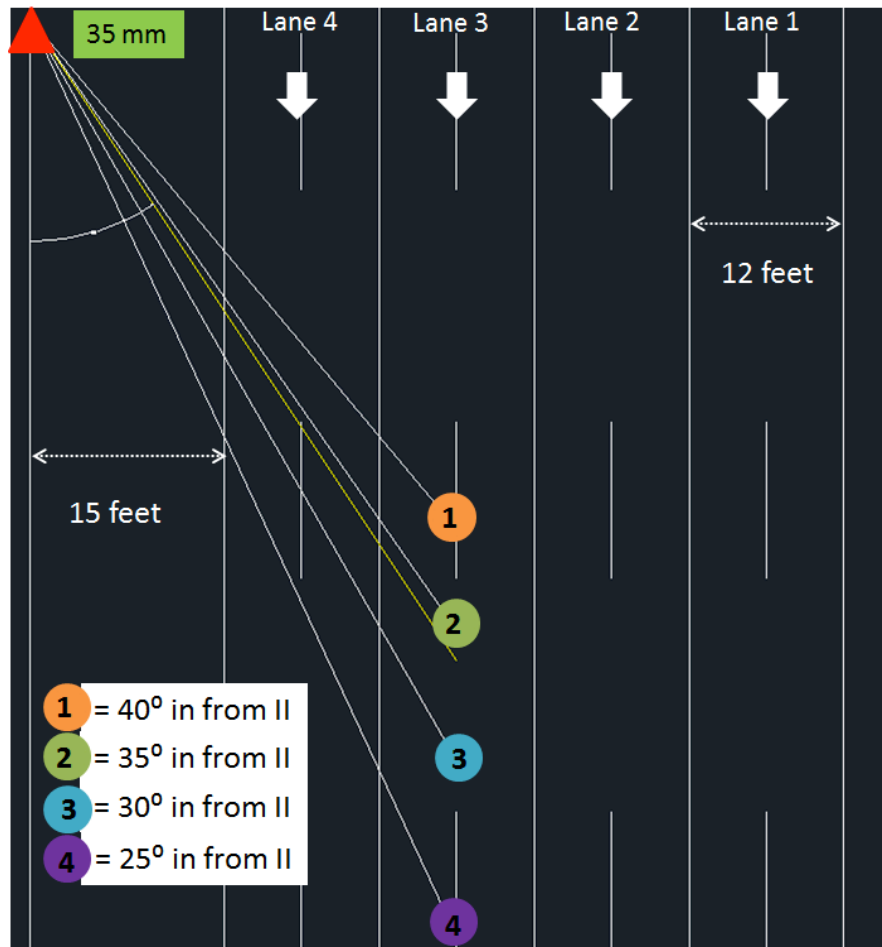
**Figure 18: Example of the ALPR camera system set-up for the I-285 freeway deployments at Paces Ferry Road**

For the first six I-285 deployments, four different camera angles were used for each ALPR camera in order to investigate the effects of camera angle on license plate accuracy and detection rate. The camera angles were measured in the field by first placing each camera parallel to the roadway so that it was facing in the downstream traffic direction while at the same time at a rotation so that the tripod angle was set to zero. Next the cameras were rotated in toward the roadway until the tripod angle was set to the desired angle. Each camera angle was tested for one quarter of each deployment period. The camera angles chosen for testing during these deployments were informed from the results of the Spring Street camera angle configuration test. During the I-285 freeway tests, the cameras were placed approximately 15 feet away from the edge of the outside travel lane whereas this distance was only approximately five feet during the

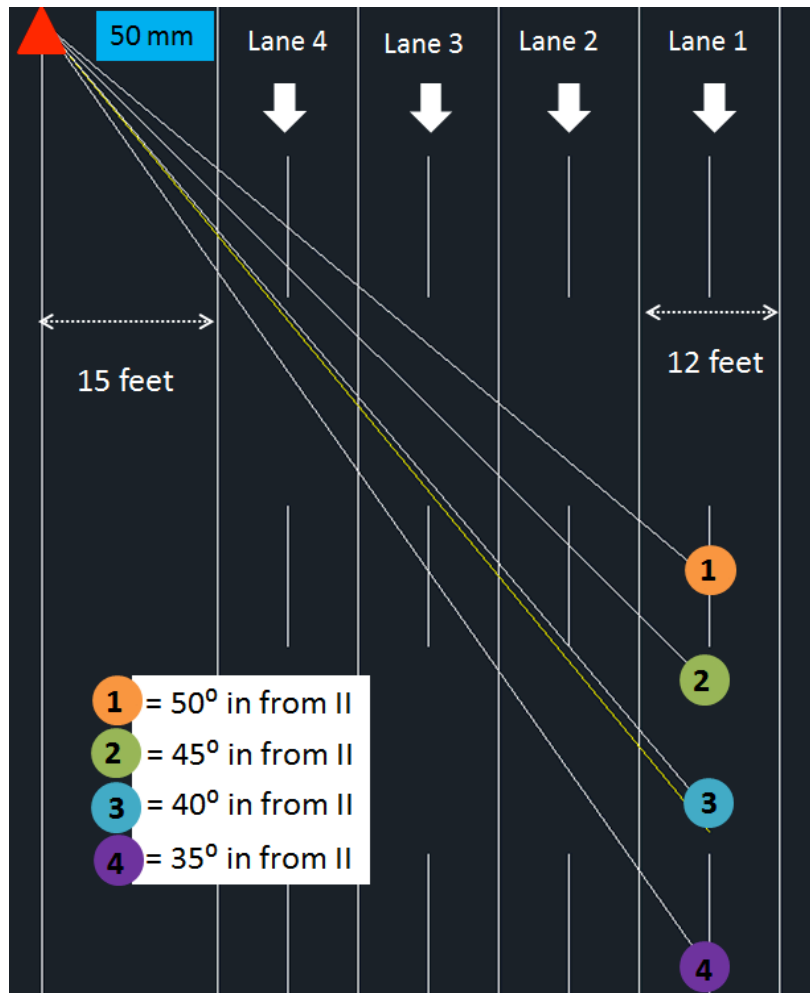
Spring Street camera angle configuration test. The 50mm camera was tested at angles of 50 degrees, 45 degrees, 40 degrees, and 35 degrees from parallel to the roadway. The 35mm camera was tested at angles of 40 degrees, 35 degrees, 30 degrees, and 25 degrees from parallel to the roadway. And the 25mm camera was tested at 45 degrees, 40 degrees, 35 degrees, and 30 degrees from parallel to the roadway. Diagrams of the four camera angles tested for each camera focal length are shown in Figures 19 – 21 below.



**Figure 19: Diagram of camera angles tested for the 25mm camera during the I-285 freeway deployments**



**Figure 20: Diagram of camera angles tested for the 35mm camera during the I-285 freeway deployments**



**Figure 21: Diagram of camera angles tested for the 50mm camera during the I-285 freeway deployments**

### 3.3.3.2 Comparative Video Cameras

For each of the six days of I-285 freeway deployment, the high definition video cameras were utilized at each site location to record vehicle license plates for manual data processing. These cameras were placed on the downstream side of the overpass bridges so that they were aimed at the back of the passing vehicles in order to record the vehicle license plates. For the I-285 deployments each camera was used to record the license plates for two freeway travel lanes at the same time so the number of cameras needed at

each site was equal to the number of travel lanes divided by two. At site locations with an odd number of freeway travel lanes, the last camera was used to record only one freeway travel lane.

For the I-285 freeway deployments freeway lanes were numbered beginning with lane zero assigned to the inside most lane and continuing out to lane three or lane four depending on the number of freeway lanes located at each site. This is a different convention than that used on the Spring Street camera angle configuration test where the inside most lane was numbered as lane one and the other lanes were number two-four. The I-285 lane numbering was chosen to match the GDOT freeway lane numbering scheme.

For the I-285 freeway deployments the high definition camera tripods were positioned with two legs on the concrete wall of the overpass and one leg on the sidewalk in order to position the camera as close to the side of the overpass as was safely possible. Figure 22 below shows an image of the camera placement on the freeway overpass during the I-285 freeway deployments. The camera views of the two lanes were set up by zooming them in completely and then panning and tilting the camera until the two freeway travel lanes were centered on the screen with the outside lines disappearing from view in the middle of the shot. Figure 23 below shows an example of the camera zoom view for a camera recording two lanes of travel. The camera views of a single lane were set up in the same way except that the lane of focus was centered in the shot with half of each of adjacent lanes in the shot as well. This shot set-up for recording one lane was necessary to ensure that the angle of view was not set up too steeply so that vehicles



would move through the view too quickly. Figure 24 below shows an example of the camera zoom view for a camera recording one lane of travel.



**Figure 22: High definition video camera tripod placement on the overpass bridges**



**Figure 23: Optimal camera zoom view for high definition cameras recording two lanes of travel**



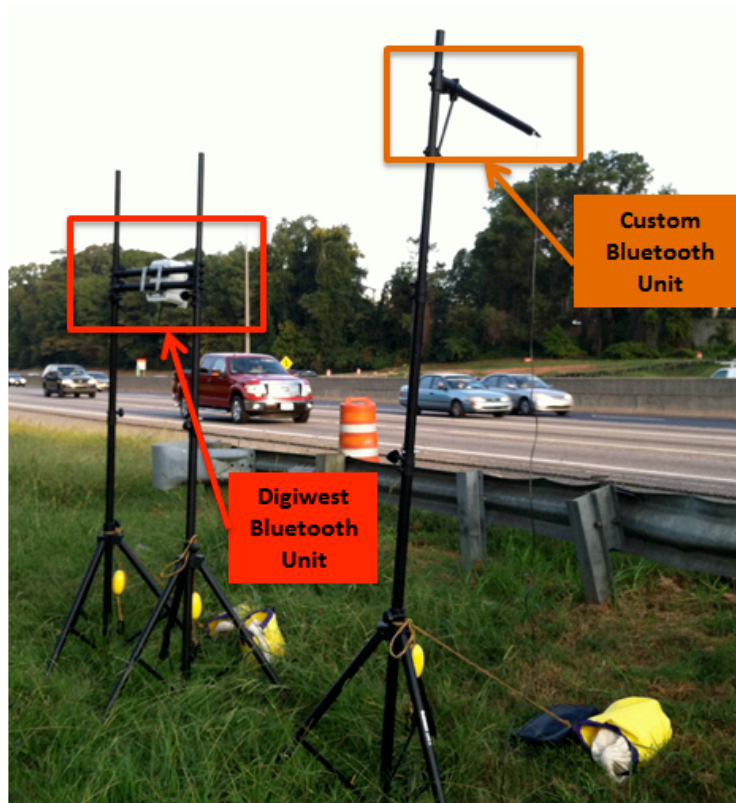
**Figure 24: Optimal camera zoom view for high definition cameras recording one lane of travel**

Also, at overpasses with chain-link fencing, additional care with camera set up was necessary to ensure that the camera view was zoomed as close to the center of one of the chain-links as possible. This step was necessary to minimize blurriness in camera footage resulting from interference from the fencing. This set-up creates the optimal camera view needed for manual license plate number entry using the video processing software, which is discussed further in Chapter 4 of this thesis.

#### 3.3.3.3 Custom & Digiwest Bluetooth Set-up

For the six days of I-285 freeway deployment, one custom Bluetooth unit was used at each ALPR site on each day of deployment. However, the Digiwest Bluetooth units were not deployed on all of the six days of I-285 freeway deployment due to issues with the units. One Digiwest Bluetooth unit was deployed to each site on September 7<sup>th</sup>, September 12<sup>th</sup>, September 29<sup>th</sup>, and November 10<sup>th</sup> and no Digiwest Bluetooth units

were deployed on September 14<sup>th</sup> and October 20<sup>th</sup>. The set up of both the custom and the Digiwest Bluetooth units involved the use of heavy-duty tripods and sand bags. The custom Bluetooth and the Digiwest Bluetooth units required different tripod configurations and pieces. The sand bags were used with both tripod configurations in order to secure the tripods and prevent them from potentially falling over. Additionally, the tripods for both types of Bluetooth equipment were set up far enough back from the edge of the freeway that if they were to fall over they would not fall into the shoulder of the freeway. A netbook was also required in the set up of the custom Bluetooth unit only. Figure 25 below shows the Bluetooth equipment set-up for the I-285 freeway deployments. A more detailed description of the Bluetooth equipment set up and configuration can be found in Stephanie Zinner's companion thesis (Fall 2012) [2].



**Figure 25: Custom and Digiwest Bluetooth set-up for the I-285 deployments**

#### 3.3.3.4 Deployment Specifics

##### *3.3.3.4.1 Day 1: Friday, September 7<sup>th</sup>, 2012*

The first weekday non-work zone deployment took place on Friday, September 7<sup>th</sup>, 2012. During this deployment the research team deployed to two sites on eastbound I-285: Paces Ferry Road and Northside Drive. A data collection team consisting of three undergraduate research assistants (URAs) and one Graduate Research Assistant (GRA) was deployed to each location. One ALPR camera system, one custom Bluetooth unit, and one Digiwest Bluetooth unit were deployed to each site location. The official start time for data collection on this day was 8:25 AM at both sites and the official data



collection end time was 10:25 AM at Paces Ferry Road and 10:35 AM at Northside Drive. The staggered end time was used to allow the last vehicles captured at Site A to reach Site B. The first ALPR camera angles were used from 8:25 AM – 8:55 AM, the second from 8:55 AM – 9:25 AM, the third from 9:25 AM – 9:55 AM, and the fourth from 9:55 AM – 10:25 AM at Paces Ferry Road and 9:55 AM – 10:35 AM at Northside Drive (see Figures 19-21). Two video cameras were set up on the overpass at Paces Ferry Road and three video cameras were set up on the overpass at Northside Drive. Figure 26 below shows a map of the data collection corridor along eastbound I-285 spanning from the interchange with Paces Ferry Road to the interchange with Northside Drive.



**Figure 26: Map of the Friday, September 7<sup>th</sup>, 2012 deployment corridor (Google Maps, 2013)**

#### *3.3.3.4.2 Day 2: Wednesday, September 12<sup>th</sup>, 2012*

The second weekday non-work zone deployment took place on Wednesday, September 12<sup>th</sup>, 2012. For this deployment the research team deployed at two sites on eastbound I-285: Northside Drive and Roswell Road. On this day the research data collection team deployed to each site consisted of two URAs and one GRA. Again, one ALPR camera system, one custom Bluetooth unit, and one Digiwest Bluetooth unit were deployed at each site location. The official start time for this data collection was 7:40 AM at both sites and the official data collection end times were 9:30 AM at Northside Drive and 9:40 AM at Roswell Road. The first ALPR camera angles were used from 7:40 AM – 8:10 AM, the second from 8:10 AM – 8:40 AM, the third from 8:40 AM – 9:10 AM, and the fourth from 9:10 AM – 9:30 AM at Northside Drive and 9:10 AM – 9:40 AM at Roswell Road (see Figures 19-21). Three video cameras were set up on both the overpass at Northside Drive and the overpass at Roswell Road. Figure 27 below shows a map of the data collection corridor along eastbound I-285 spanning from the interchange with Northside Drive to the interchange with Roswell Road.

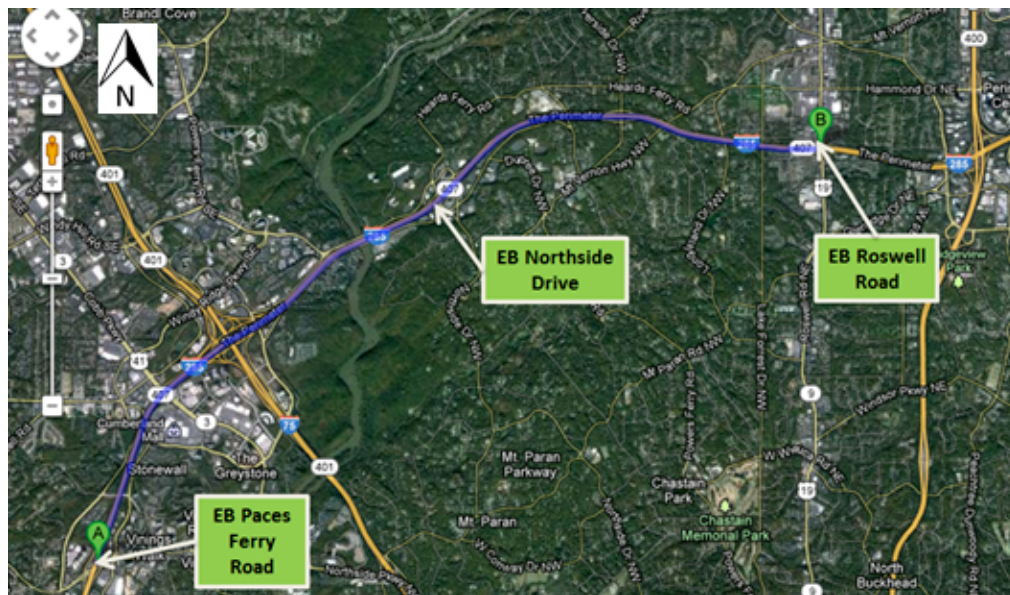


**Figure 27: Map of the Wednesday, September 12<sup>th</sup>, 2012 deployment corridor (Google Maps, 2013)**

#### *3.3.3.4.3 Day 3: Friday, September 14<sup>th</sup>, 2012*

The third weekday non-work zone deployment took place on Friday, September 14<sup>th</sup>, 2012. On this day the research team deployed to three site locations on eastbound I-285: Paces Ferry Road, Northside Drive, and Roswell Road. Three site locations were chosen for this deployment to add in an intermediate travel time station in order to collect more robust travel time data through this corridor. One custom Bluetooth unit was deployed at the three sites, one ALPR camera system was deployed at two sites (Northside Drive and Roswell Road), and no Digiwest Bluetooth units were deployed. Because there were only two ALPR camera systems available, they could only be deployed to two sites; Northside Drive and Roswell Road were chosen since they do not have a major interchange between them, as exists between Paces Ferry Road and Northside Drive. The official start time for this data collection was 7:35 AM at all sites and the official data collection end times were 9:30 AM at Paces Ferry Road, 9:35 AM at

Northside Drive, and 9:40 AM at Roswell Road. The first ALPR camera angles were used from 7:35 AM – 8:05 AM, the second from 8:05 AM – 8:35 AM, the third from 8:35 AM – 9:05 AM, and the fourth from 9:05 AM – 9:35 AM at Northside Drive and from 9:05 AM – 9:40 AM at Roswell Road (see Figures 19-21). During this deployment, three video cameras were set-up on both the Northside Drive and the Roswell Road overpasses. These two sites were chosen to coincide with the placement of the ALPR cameras. Figure 28 below shows a map of the data collection corridor on eastbound I-285 spanning from the interchange with Paces Ferry Road to the interchange with Roswell Road.

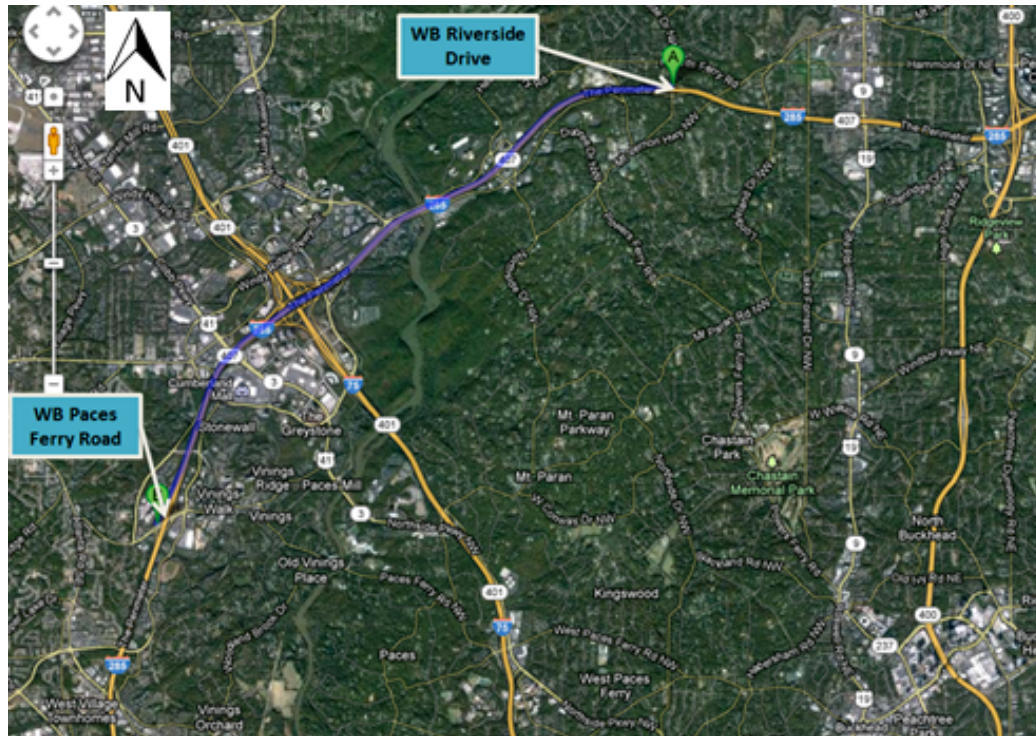


**Figure 28: Map of the Friday, September 14<sup>th</sup>, 2012 deployment corridor (Google Maps, 2013)**



#### *3.3.3.4.4 Day 4: Saturday, September 29<sup>th</sup>, 2012*

The first day of weekend active work-zone deployment took place on Saturday, September 29<sup>th</sup>, 2012. For this day the reported lane closures for construction were the three inside lanes on eastbound I-285 between Roswell Road and Ashford Dunwoody Road and the three inside lanes on westbound I-285 from Roswell Road to Paces Ferry Road. Constrained to the previously identified suitable deployment locations, the research team decided to deploy to two site locations on westbound I-285: Riverside Drive and Paces Ferry Road. After arriving to the site locations on the day of deployment, the research team found that the lane closure locations had been modified and that the chosen site locations would not be able to measure travel times through the active work zone corridor. However, the research team decided to proceed with the deployment as planned at westbound Riverside Drive and westbound Paces Ferry Road. Figure 29 below shows a map of the data collection corridor on westbound I-285 spanning from the interchange with Riverside Drive to the interchange with Paces Ferry Road.



**Figure 29: Map of the Saturday, September 29<sup>th</sup>, 2012 deployment corridor (Google Maps, 2013)**

One ALPR camera system, one custom Bluetooth unit, and one Digiwest Bluetooth unit were deployed to each site location during this deployment. The official start time for this data collection was 7:40 AM at both site locations and the official end time for data collection was 10:40 AM at Riverside Drive and 10:50 AM at Paces Ferry Road. The first ALPR camera angles were used from 7:40 AM – 8:25 AM, the second from 8:25 AM – 9:10 AM, the third from 9:10 AM – 9:55 AM, and the fourth from 9:55 AM – 10:40 AM at Riverside Drive and 9:55 AM – 10:50 AM at Paces Ferry Road (see Figures 19-21). During this deployment, two video cameras were set up on the Paces Ferry Road overpass and three video cameras were set up on the Riverside Drive overpass.

#### *3.3.3.4.5 Day 5: Saturday, October 20<sup>th</sup>, 2012*

The second day of weekend active work-zone deployment took place on Saturday, October 20<sup>th</sup>, 2012. For this day the targeted lane closure was one mile of the leftmost inside lane on westbound I-285 from Powers Ferry Road (just after Riverside Drive in the westbound direction) to Northside Drive. To capture this work zone, the research team planned to deploy to westbound Riverside Drive and westbound Paces Ferry Road. However, upon arrival to the deployment site locations, the research team found that the lane closure schedule had again been modified. The new lane closures were the two rightmost lanes on eastbound I-285 from just after Paces Ferry Road to the junction with I-75, including a closure of the eastbound access ramp to I-75. On the day of deployment, the research team was able to change the research plan and deployed instead to eastbound Paces Ferry Road and eastbound Northside Drive in order to capture the congestion from this active work zone. Figure 30 below shows a map of the data collection corridor on eastbound I-285 spanning from the interchange with Paces Ferry Road to the interchange with Northside Drive.



**Figure 30: Map of the Saturday, October 20<sup>th</sup>, 2012 deployment locations (Google Maps, 2013)**

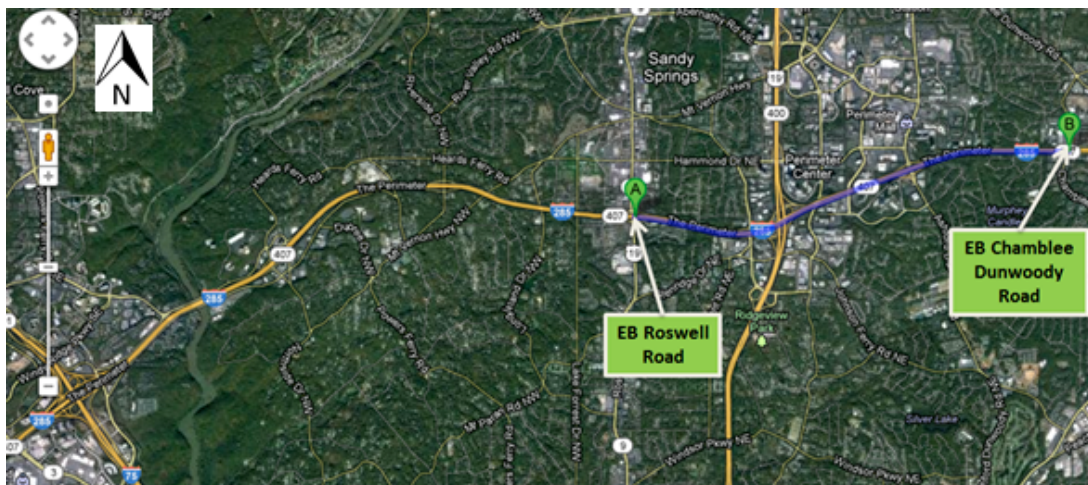
For this deployment, one ALPR system and one custom Bluetooth unit were deployed to each site location and no Digiwest Bluetooth units were deployed. Two video cameras were set up on the overpass at Paces Ferry Road and three video cameras were set up on the overpass at Northside Drive. The official data collection start time was 9:52 AM for both locations and the official data collection end time was 12:32 PM at Paces Ferry Road and was 12:52 PM at Northside Drive. The first ALPR camera angles were used from 9:52 AM – 10:32 AM, the second from 10:32 AM – 11:12 AM, the third from 11:12 AM – 11:52 AM, and the fourth from 11:52 AM – 12:32 PM at Paces Ferry Road and from 11:52 AM – 12:52 PM at Northside Drive (see Figures 19-21). The buffer time between the end of data collection at Paces Ferry Road and the end of data



collection at Northside Drive was increased to 20 minutes for this deployment to account for the increased travel times due to the congestion from the active work zone.

#### *3.3.3.4.6 Day 6: Saturday, November 10<sup>th</sup>, 2012*

The third day of weekend active work zone deployment took place on Saturday, November 10<sup>th</sup>, 2012. The targeted lane closure for this day was two right lanes on eastbound I-285 from Peachtree Dunwoody Boulevard to Glenridge Drive, which are the two interchanges located on either side of the interchange of GA-400 and I-285. To capture the active work zone conditions through this corridor, the research team chose to deploy to two locations on eastbound I-285: Roswell Road and Chamblee Dunwoody Road. Upon arriving to the deployment locations on the day of deployment the research team again learned that the lane closure plan had been altered; however, the research team decided to continue with the deployment as scheduled. Figure 31 below shows a map of the data collection corridor spanning along eastbound I-285 spanning from the interchange with Roswell Road to the interchange with Chamblee Dunwoody Road.



**Figure 31: Map of the Saturday, November 10<sup>th</sup>, 2012 deployment locations (Google Maps, 2013)**

One ALPR camera system, one custom Bluetooth unit, and one Digiwest unit were deployed to each of the two site locations. During this deployment, three videos cameras were set up on both the overpass at Roswell Road and the overpass at Chamblee Dunwoody Road. The official data collection start time was 8:40 AM for both site locations and the official data collection end time was 10:40 AM at Roswell Road and was 10:50 AM at Chamblee Dunwoody Road. The first ALPR camera angles were used from 8:40 AM – 9:10 AM, the second from 9:10 AM – 9:40 AM, the third from 9:40 AM – 10:10 AM, and the fourth from 10:10 AM – 10:40 AM at Roswell Road and from 10:10 AM – 10:50 AM at Chamblee Dunwoody Road (see Figures 19-21).

## CHAPTER 4

### DATA PROCESSING METHODOLOGY

#### *4.1 Camera Angle Configuration Test*

##### **4.1.1 Manual Video Processing**

The high definition video camera footage collected during the camera angle configuration test on Spring Street was manually processed without the aid of video processing software. One URA watched each of the two videos and recorded the license plate number of each passing vehicle in an Excel table in columns corresponding to each vehicle's lane of travel. URAs also indicated "miss" for any vehicle license plates that they were unable to read for various reasons such as occlusion by another vehicle or obstruction from an object on the vehicle, such as a trailer hitch, bike rack, etc. While processing the videos, the URAs also indicated the state of the vehicle license plate if the plate was from a state other than Georgia and also categorized the license plate as a temporary license plate or no license plate if necessary.

Given the video camera set up (left camera recording lanes one – three and right camera recording lanes two – four), the processed license plate data was duplicated by the URAs for lanes two and three. Therefore, the next step in the data processing was to manually compare and combine the duplicated license plate data from lanes two and three in order to check for consistency in plate number recordings and to combine

“misses” from one video that were able to be recorded as plate numbers from the other video due to a different view angle.

#### **4.1.2 ALPR Output Processing**

After the completion of the camera angle configuration test on Spring Street, the license plate data collected by the ALPR camera system was exported from the Car System ® program as an HTML file. The columns of the HTML file containing the date/time of plate capture, camera of capture, and license plate read were copied into an Excel database (see Figure 35 for an image of the Car System ® HTML output file). Within Excel, the data was sorted into ascending time order and the license plate number data was color coded according to which ALPR camera produced it (i.e. 25mm, 35mm, 50mm).

As a step in the data processing procedure for the ALPR data collected during the I-285 freeway tests (discussed in a later section of this thesis), the ALPR license plate data was manually processed by visually checking the infrared license plate images from the ALPR output to produce a list of accurate license plate numbers. This allowed for a comparison of the ALPR OCR (Optical Character Recognition) output to a manual read of the same image.

#### **4.1.3 Manual ALPR & Video License Plate Matching**

After both the high definition video footage and the ALPR data had been processed into Excel tables containing all of the license plate recordings in ascending time order, the corresponding license plate number records could be manually matched



across the two data sources. The video license plate data was split into twelve separate Excel tables corresponding to the twelve different vehicle lane and camera angle time periods (4 lanes x 3 camera angles) and the ALPR license plate data was split into three separate Excel tables corresponding to the three different camera angle time periods, as the ALPR data does not allow for direct identification of lane. Matching the plates across the two data sets involved visually matching each ALPR license plate record to its corresponding license plate record in the output from the processed videos.

If the processor was unable to visually identify which video license plate record an ALPR record corresponded to due to errors or uncertainty in the ALPR license plate read, they looked at the infrared license plate image from the ALPR output to aid with the matching. The ALPR infrared license plate images were also used to verify whether an ALPR record was from a license plate or from some other image such as words on the side of a truck. By the end of the manual matching process, every ALPR license plate record was either matched to a license plate record from the video processing output or was identified as a reading of something other than a license plate. Later efforts expedited this manual matching process by developing license plate matching algorithms to process the license plate data collected during the I-285 freeway tests.

#### **4.1.4 ALPR Detection Rate Analysis**

Once all of the ALPR license plate records were matched with their corresponding video license plate records, the ALPR system's vehicle detection rates were calculated by dividing the number of ALPR license plate detections by the total number of vehicles passing the site. Detection rates were produced for each camera,

travel lane, and angle combination – producing 36 total detection rates. This allows for an analysis of each camera focal length for each lane and angle. The results of the detection rate analysis from the Spring Street camera angle configuration test are presented in section 5.1.1.

#### **4.1.5 ALPR Accuracy Analysis**

Accuracy results were also produced for each camera, lane, and camera angle combination. The accuracy of each ALPR license plate record was manually assessed by visually comparing the ALPR license plate record to the license plate record from the video processing. The license plate numbers produced during the video processing were taken to be accurate based on a QA/QC analysis (discussed in section 4.2.2.3). Each license plate record from the video processing was either captured by the ALPR cameras or missed by them. If an ALPR camera missed a vehicle license plate, a “miss” was coded in the accuracy assessment. No instances of the ALPR cameras capturing a license plate that was not recorded in the manual video processing were identified.

After the missed license plates were identified, the accuracy of the captured ALPR license plate records were described in terms of how many license plate digits were “bracketed” (declaring uncertainty by the ALPR software), incorrect, or missing. The license plate reading algorithm within the ALPR system “brackets” digits when the algorithm cannot distinguish the digit’s exact character. For example, if the ALPR system cannot determine whether a digit is a B or an 8, it will return “[B8]” in the place of that digit. Within the accuracy analysis, these bracketed errors were coded as “bracketed-x” with “x” being the number of digits in the ALPR license plate record that

received brackets from the ALPR system plate reading algorithm. Incorrect digits were those that the ALPR system license plate algorithm identified incorrectly or that the algorithm incorrectly inserted into the license plate number record. Within the accuracy analysis, incorrect digits were coded as “incorrect-x” with x being the number of digits in the ALPR license plate record that were incorrect. Missing digits were those that the ALPR system license plate algorithm completely left out of the license plate number record. Within the accuracy analysis, these missing digits were coded as “partial-x” with x being the number of digits in the correct license plate number that were missing from the ALPR license plate record. If no portions within an ALPR license plate number fell into any of these three categories, that ALPR license plate record is coded as “correct”. The results of the accuracy analysis from the Spring Street camera angle configuration test are presented in section 5.1.2.

#### *4.2 I-285 Freeway Deployments*

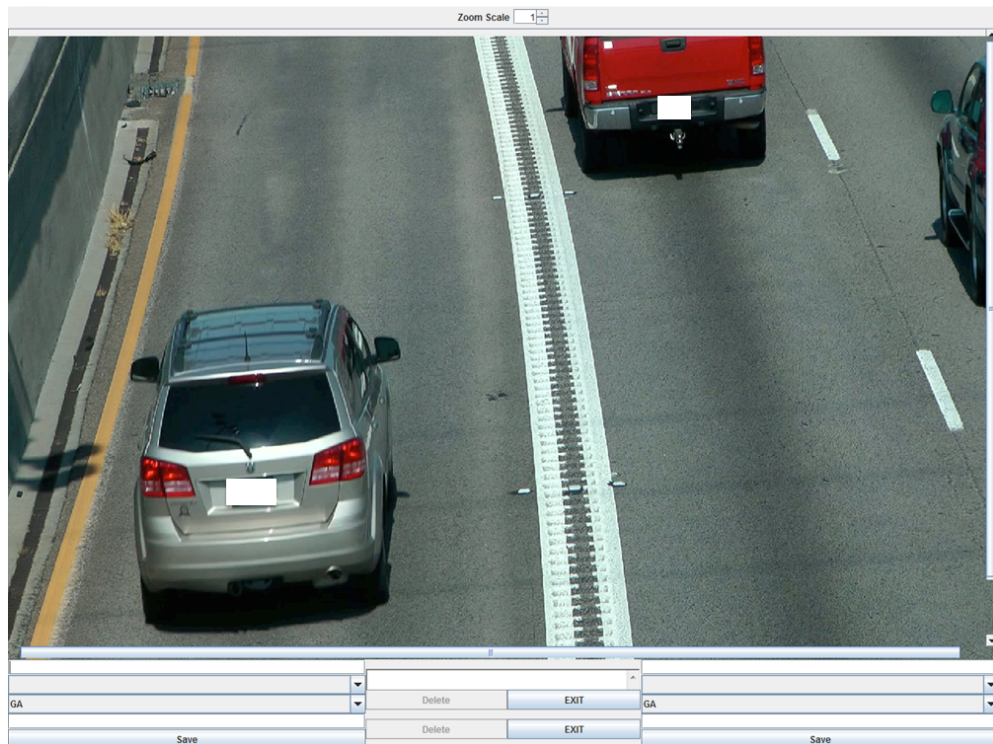
Due to the extensive time involved in processing the data collected during the I-285 freeway deployments, the full data processing efforts were only conducted for the data collected during the September 7<sup>th</sup>, 2012, October 20<sup>th</sup>, 2012, and November 10<sup>th</sup>, 2012 deployments. Additionally, the travel time portion of the data processing effort was conducted for the April 13<sup>th</sup>, 2013 large-scale deployment with plans to complete the other portions of the data processing for this deployment in the future. The details of each component of the data processing effort from the I-285 freeway deployments are discussed in the sections below.

#### **4.2.1 Manual Video Processing**

Because the I-285 freeway deployments involved much larger vehicle volumes than the Spring Street deployment, the high definition video footage from these deployments were processed using the aid of a proprietary video-processing program that was developed at Georgia Tech. This video-processing program was originally used on a project involving a corridor with a high occupancy toll (HOT) lane so the program requires a lane numbering convention that starts with numbering the inside most lane (HOT lane) as lane zero and numbering up to lane four or five moving towards the outside lanes. Because of the video-processing program requirement, the lane numbering convention was switched from the convention used for the Spring Street camera angle configuration test (inside most lane numbered as lane one) to the new convention (inside most lane numbered as lane zero).

The high definition video files collected during the field deployments were downloaded and given new file names according to a specific convention. An example of the file naming convention is “PFR\_LP\_AM\_L0L1\_20120907\_082328\_00213” where PFR is the site (Paces Ferry Road), LP is License Plate, AM is morning period, L0L1 is Lane 0 and Lane 1, 20120907 is the date, 082328 is the end time of the video file, and 00213 is the video file number. The end time of a video file is found by viewing the properties for the file and looking at the time specified as “modified.” After the renaming process, the video files were run through a freeware program called Free Video to JPG Converter available through DVDVideoSoft. This program reduces the video files to screen shots of every 30<sup>th</sup> frame, which is equivalent to two frames per second.

Next, the reduced video images were sent through the video-processing program. The video-processing program uses reduced images from the videos rather than the videos themselves because this allows video processors to tab through the images rather than needing to pause and re-start a video file, which results in faster processing times. The video-processing program has a user interface that allows processors to enter the license plate number, type of vehicle, and license plate state for each vehicle seen in the images. Figure 32 below shows an image of the license plate video-processing program interface.



**Figure 32: The user interface of Georgia Tech's proprietary license plate video-processing program**

The video-processing program automatically assigns the date, site location, vehicle lane, and time stamp of to each input vehicle, which the program pulls from the

file name of each video file. The time stamps are assigned to vehicles using the end time of the video file (from the file name) and counting backwards in time using the frame number as a proxy for elapsed time. The video processors input the vehicle license plate numbers to the best of their ability and indicate difficult to read license plate digits as question marks. The type of vehicle is only input if the vehicle is a motorcycle and the license plate state is only input if the license plate is from a state other than Georgia. If a license plate is completely unreadable or blocked by another vehicle or object, the video processors input the word “miss” into the box for the license plate number, which is necessary to allow for accurate total vehicle counts. Additionally, video processors input specific information about the reason for license plate obstructions such as the presence of trailer hitches, bike racks, etc.

The high definition video cameras create multiple video files during a single field deployment because file size limits cap each video file length at approximately 22 minutes. The video-processing program processes each video file separately and therefore creates a separate output Excel file for each video file. After the component video files of each full video were processed, their data was compiled into a single Excel file for each site for each day that contained separate tabs for the license plate data from each video camera from that site and day.

#### 4.2.1.1 Video File Creation Time Corrections

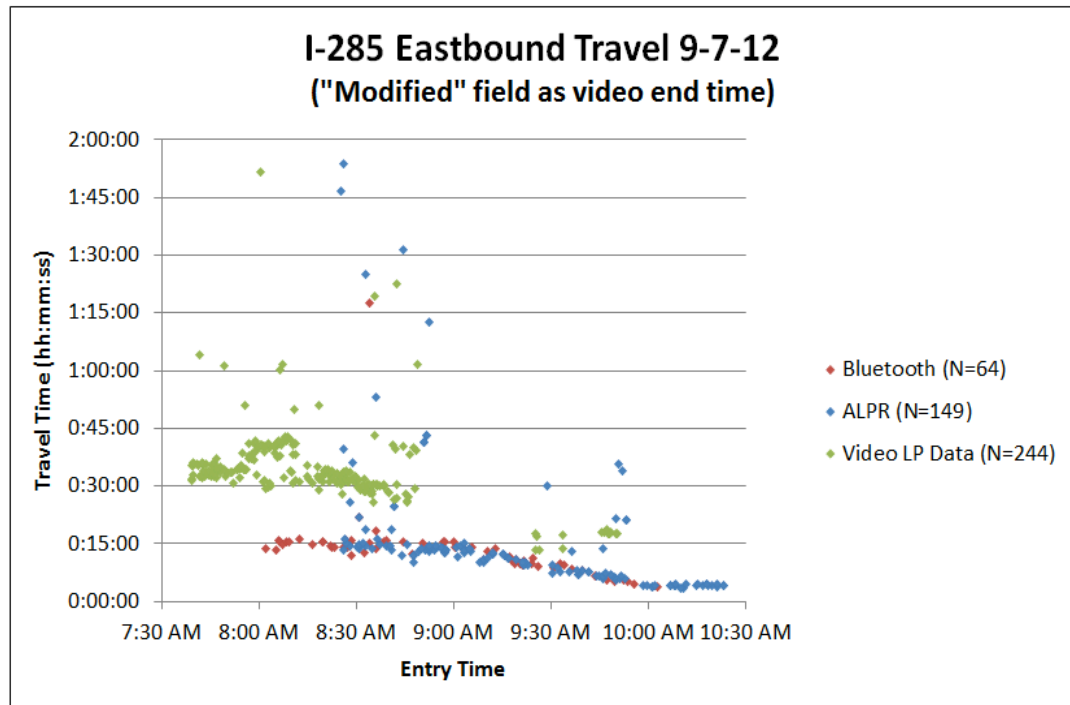
During the data compilation process it was identified that there was an issue with the video file end times for the video data collected during the September 7<sup>th</sup>, 2012 and September 12<sup>th</sup>, 2012 field deployments. Further investigation revealed that a video file’s

“modified” field is not always equivalent to the end time of the video. Depending on the file system, the “modified” field may either be the time of the last status change (video end time) or the file creation time (video start time). It was identified that the video files collected on September 7<sup>th</sup> and September 12<sup>th</sup> have “modified” fields that reflect the video file start time and that the video files collected on the remaining five days, September 14<sup>th</sup>, September 29<sup>th</sup>, October 20<sup>th</sup>, November 10<sup>th</sup>, and April 13<sup>th</sup>, have “modified” fields that reflect the video file end time. The implication of this difference is that the time stamps assigned to vehicle inputs by the video-processing program for September 14<sup>th</sup>, September 29<sup>th</sup>, October 20<sup>th</sup>, November 10<sup>th</sup>, and April 13<sup>th</sup> were correct, but the time stamps for the September 7<sup>th</sup> and September 12<sup>th</sup> videos needed to be adjusted.

The incorrectly assigned time stamps had to be adjusted on a per video file basis. Inputting video file start times rather than video file end times into the video-processing program resulted in the assigning of vehicle time stamps that were too early. The amount that the incorrectly assigned time stamps were too early was equivalent to the length of that particular video file. Therefore, to correct the time stamps, the length of each video file was added to the incorrect time stamps in order to establish the correct time stamps. An example of the start time/end time correction is shown in Figures 33 and 34 below. Figure 33 shows the travel time plot from the September 7<sup>th</sup> deployment using the incorrect time stamps that were output from the video-processing program and Figure 34 shows the same travel time plot using the corrected time stamps. The data points that change between the two plots are the green data points, which represent the travel times calculated from the video data. In the second plot, a large gap between the travel times

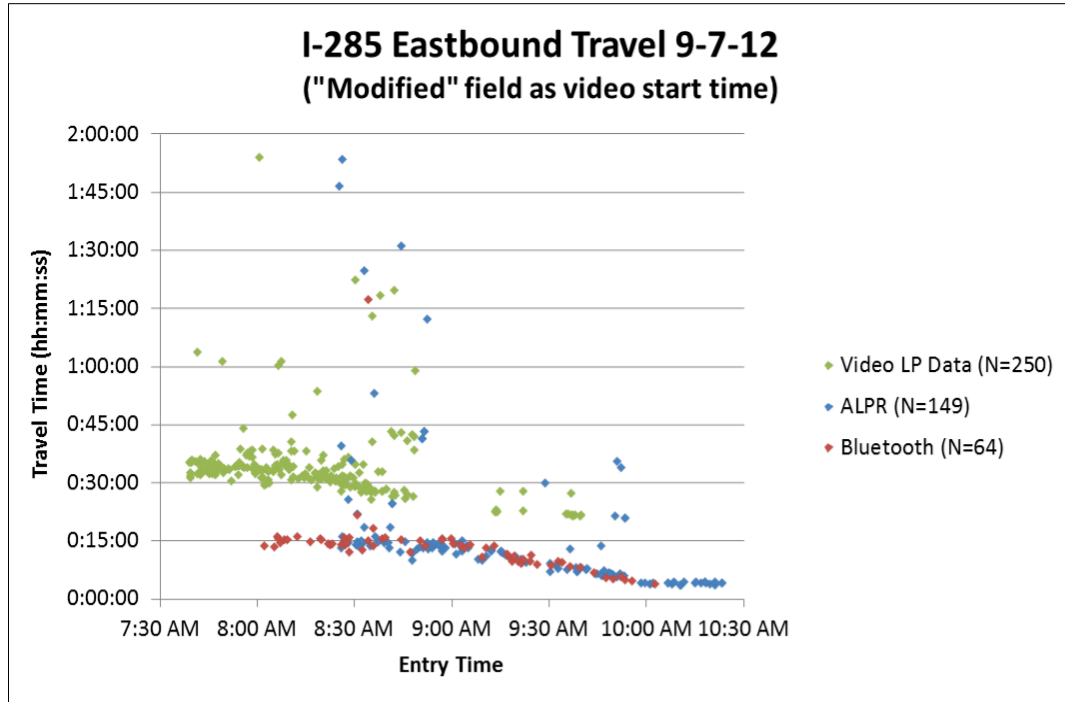
from the video data and the travel times from the ALPR and Bluetooth data can be seen.

This gap is a result of an issue with the internal time settings on the high definition cameras, the correction of which will be discussed in section 4.2.5.



**Figure 33: Raw video processing data from September 7<sup>th</sup>, 2012 where the “modified” field is used as the video file end time**





**Figure 34: Corrected video processing data from September 7<sup>th</sup>, 2012 where the “modified” field is used as the video file start time**


#### 4.2.2 ALPR Output Processing

After the completion of the I-285 field deployments, the ALPR license plate data was exported as an HTML file from the Car System ® program using a time and date range query. The exported data set contained the raw license plate read, the time and date stamp, the camera of capture, the black and white infrared license plate image, and the color license plate image for each vehicle license plate captured. The columns containing the raw license plate read, time and date stamp, and camera capture information were exported into Excel for data analysis purposes.


#### 4.2.2.1 Establishing Correct ALPR License Plate Numbers

In order to prepare the raw ALPR license plate records from the data collected during the I-285 freeway tests for an accuracy assessment, the correct license plate numbers were established for comparison. One method of establishing the correct license plate numbers was to use the license plate numbers from the video-processing program output. This method was not utilized because an additional step of matching the raw ALPR license plate records to the video-processing license plate records would be required. The alternative method chosen was to utilize the black and white infrared license plate images from the ALPR output data to establish the correct license plate numbers.

To prepare for this data processing effort, the ALPR output data HTML script was altered to automatically display the black and white license plate images within the web page in order to eliminate the previous requirement of clicking to open each infrared image. Additionally, an Excel file was set up to contain the ALPR license plate records, data and time stamps, and camera of capture information in the same descending time order as in the HTML file so that the process of inputting the correct license plate numbers was simplified. With the HTML file and the Excel file open side by side, data processors were then able to manually type the correct license plate numbers into the Excel file by visually identifying the correct license plate numbers from the infrared images. An example of this data processing set-up is shown in Figures 35 and 36 below.

Date/Time	Plate	State	Reader	Lat	Long	Alarm Flag	Note	Image
11/10/2012 10:39:59 AM		?	Top50	0.000000	0.000000	TRANSIT	Not available	

**Figure 35: Example of an ALPR output HTML file modified to display the infrared license plate images within the browser**

Date & Time	Camera	ALPR Plate Read	Correct Plate Number NC = not clear NP = not a plate	Truck? T = tractor trailer truck	OS = Out of State VP = Vanity Plate SP = Special Plate Temp = Temporary	Notes
11/10/2012 10:39	Top50					
11/10/2012 10:39	Top50				OS	
11/10/2012 10:39	Right25				OS	
11/10/2012 10:39	Left35				OS	
11/10/2012 10:39	Top50					
11/10/2012 10:39	Top50					
11/10/2012 10:39	Top50					
11/10/2012 10:39	Top50					
11/10/2012 10:39	Top50					
11/10/2012 10:39	Left35					
11/10/2012 10:39	Left35					
11/10/2012 10:39	Right25					
11/10/2012 10:39	Top50					
11/10/2012 10:39	Top50					
11/10/2012 10:39	Top50					
11/10/2012 10:39	Top50					
11/10/2012 10:39	Right25				SP	
11/10/2012 10:39	Left35					
11/10/2012 10:39	Left35					
11/10/2012 10:39	Top50					
11/10/2012 10:39	Right25					
11/10/2012 10:39	Top50					
11/10/2012 10:39	Top50					
11/10/2012 10:39	Left35					
11/10/2012 10:39	Left35					
11/10/2012 10:39	Left35					
11/10/2012 10:39	Right25					
11/10/2012 10:39	Left35					
11/10/2012 10:39	Top50					

**Figure 36: Example of the Excel file set-up for the input of the correct vehicle license plate numbers**

#### 4.2.2.2 Categorizing License Plate Reads

At the same time that the data processors manually typed the correct license plate numbers into the Excel table they also categorized the license plates into several categories including tractor-trailer trucks (T), out-of-state plates (OS), vanity plates (VP), special plates (SP), and temporary plates (TEMP), as can be seen in the table column headings in Figure 40 above. An additional category, “non-plate” (NP), was added because the ALPR cameras sometimes take pictures of numbers or words on the sides or backs of vehicles that are not license plate numbers. For non-plate reads processors were also instructed to indicate a T in the tractor-trailer column if the non-plate read was associated with a truck. Another category, “not clear” (NC), was added for ALPR license plate records from which the full correct license plate number could not be established because the ALPR cameras either took a partial picture of a license plate or because the license plate number was partially blocked in the image by an object. Additionally, data processors were asked to identify duplicated plate reads (due to license plates being captured by more than one ALPR camera) by adding color to the cells containing duplicate plate information. The cells containing the plate read information from the first capture were left with no fill and only the one or two duplicate records were colored.

#### 4.2.2.3 Quality Assurance & Quality Control

To save time and to improve the accuracy of the manually typed correct plate numbers, student data processors initially copied the data in the ALPR system raw plate records column into the corrected plate read column so that they could edit these plate numbers as needed rather than typing each correct plate number from scratch.

Additionally, a quality assurance and quality control assessment of the accuracy of the

corrected license plate numbers column and the other category columns was conducted by assigning a second data processor to review the work of the original data processor for 1000 records of two data sets. In the 1000 records checked in both data sets, less than one percent of the data contained an error.

#### **4.2.3 License Plate Matching Algorithm**

License plate matching algorithms were created and utilized for the accuracy assessment, for the travel time comparison assessment, and for assigning ALPR license plate reads to their associated freeway travel lanes. The travel time algorithms were designed to find matches between the license plate data from one site and the license plate data from another site. The travel time algorithms were also useful for establishing ALPR license plate lane assignments.

##### **4.2.3.1 Exact Matches Travel Time Algorithm**

The travel time algorithm was designed to identify matches between two sites that were either exact matches or matches created from plate numbers containing bracketed digits. This algorithm handles bracketed license plate number digits by creating all of the possible plate numbers that can be made from combinations of those bracketed digits. For example, if a raw plate read contains one set of brackets with three digits inside the brackets, the algorithm will create three different possible license plate numbers for this raw plate read. If a raw plate read contains two sets of brackets – one with three digits and one with two digits inside the brackets, the algorithm will create six ( $3 \times 2$ ) different possible license plate numbers for this raw plate read. For each site, the algorithm creates a list containing both the plate reads that had no brackets and the combinations of plate

numbers made from the plate numbers that had brackets. Finally, the algorithm finds matches between the two sites from these two lists of plate numbers.

This algorithm also removes duplicated matches, which either occur when multiple cameras capture the same license plate or when the same vehicle drives through the corridor more than once during the data collection time period. The purpose of the removal of duplicated plates is to remove those that were captured by multiple cameras and an unwanted effect of the removal of all duplicated plates is that plate numbers belonging to vehicles travelling through the corridor more than once are also removed. This effect could be eliminated in subsequent algorithms by implementing a time window in which duplicated plates will be removed from the data set.

#### **4.2.4 ALPR License Plate Record Lane Assignments**

The assignment of ALPR license plate reads to their respective freeway travel lanes is necessary in order to investigate the ability of each of the three cameras to accurately read license plates in each of the freeway travel lanes. The initial method used to accomplish this lane assignment was to use the exact matches travel time algorithm to find matches between the ALPR license plate records and the video-processing license plate records from the same data collection location. However, there were some drawbacks with this method such some of the subsequent ALPR license plate lane assignments could be incorrect due to vehicles changing lanes between the point of ALPR camera system capture (roadside upstream of the overpass) and the point of video camera capture (downstream of the overpass). Also this method could only assign lanes to ALPR license plate records that were able to be matched to video-processing license

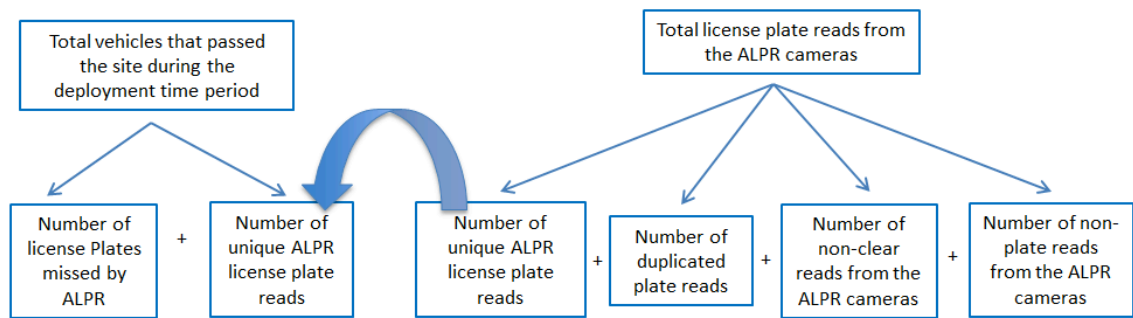
plate records with the exact matches algorithm, which left many ALPR license plate records without lane number assignments.

It was determined that for the work of this thesis, the detection rate results from the I-285 freeway tests could be analyzed on a per camera angle basis, but not on a per lane number basis since the lane numbers could not be determined for some of the ALPR license plate records. Also, it is important to note that the vehicle lanes of travel for the ALPR license plate records were not able to be reliably determined from the color license plate image output or the black and white infrared license plate image output from the Car System ® program because of the camera angle and the field of view of the images. Another method for identifying the lane number of travel for the ALPR license plate records could be to use the pixel size information from the Car System ® output with the premise that there will be a distinct difference in the pixel size of license plate images in each travel lane for each focal length camera. This method was not utilized in this thesis, but could be employed in further research on this subject.

#### **4.2.5 ALPR Detection Rate Analysis**

Once the processing of the video files and the ALPR license plate records were completed, the data was then ready for the detection rate analysis. To perform the detection rate analysis, the number of processed ALPR license plate records in each of the following four categories was counted: non-plate reads, non-clear plate reads, duplicated plate reads, and unique plate reads. Non-plate reads, non-clear plate reads, and duplicated plate reads were identified during the processing of the ALPR license plate records. Then, number of unique plate reads was calculated by subtracting the total number of reads in the other three categories from the total number of raw ALPR license

plate records. Next, the count of the total number of vehicles passing a particular site during a particular deployment was calculated by summing the total number of license plate records output from the video processing for all videos recorded at that site on that day. This total sum included the license plates that were not able to be read during the manual video processing. Finally, to calculate the detection rate for each site, the total number of unique ALPR license plate reads from that site was divided by the total number of vehicles that passed that site during the deployment time period. A schematic of the detection rate analysis is shown in Figure 37 below and the results are presented in section 5.2.1.



**Figure 37: Schematic of the flow of the detection rate categories**

For the I-285 freeway deployments, the detection rate analysis was only performed on an overall site detection rate basis for each of the sites involved in each of the deployments. An analysis of variations in the detection rate associated with the four different camera angles tested during the six I-285 deployments was decided against because the changing congestion conditions throughout the deployment periods would interfere with an unbiased comparison between the detection rates for the four camera angle time periods. Additionally, an analysis of the detection rates for each of the vehicle



lanes of travel was not conducted as ALPR license plate reads could not be assigned to a travel lane. This analysis could be undertaken in future research if the method of using the pixel size information from the ALPR images to determine the vehicle lanes of travel is successful.

#### **4.2.6 ALPR Accuracy Analysis**

Due to time limitations, the ALPR accuracy assessment of the data collected during the I-285 freeway deployments could not be conducted. However, an analysis of the ALPR license plate read accuracy could be conducted in future analyses using scripting to compare the raw ALPR license plate reads to the corrected ALPR license plate reads from the ALPR data processing.

#### **4.2.7 Video Camera Internal Time Corrections**

One challenge of the field data collection was that the internal times of the high definition video cameras were not synched prior to each of the six I-285 freeway deployments. This had the effect of either lengthening or shortening the travel times by the length of time difference in the internal camera times of the cameras that captured each vehicle at the two site locations. The impact of this issue on the video travel times can be seen in the previously shown Figures 33 and 34.

Two methods were used to identify the gap between the internal camera time and the correct time for each camera during each deployment. The first method utilized the ALPR time stamps to compute the differences between the ALPR time stamps and the video time stamps for matched vehicles. The second method utilized weaving vehicles to compute the camera-to-camera time differences. The second method was necessary for

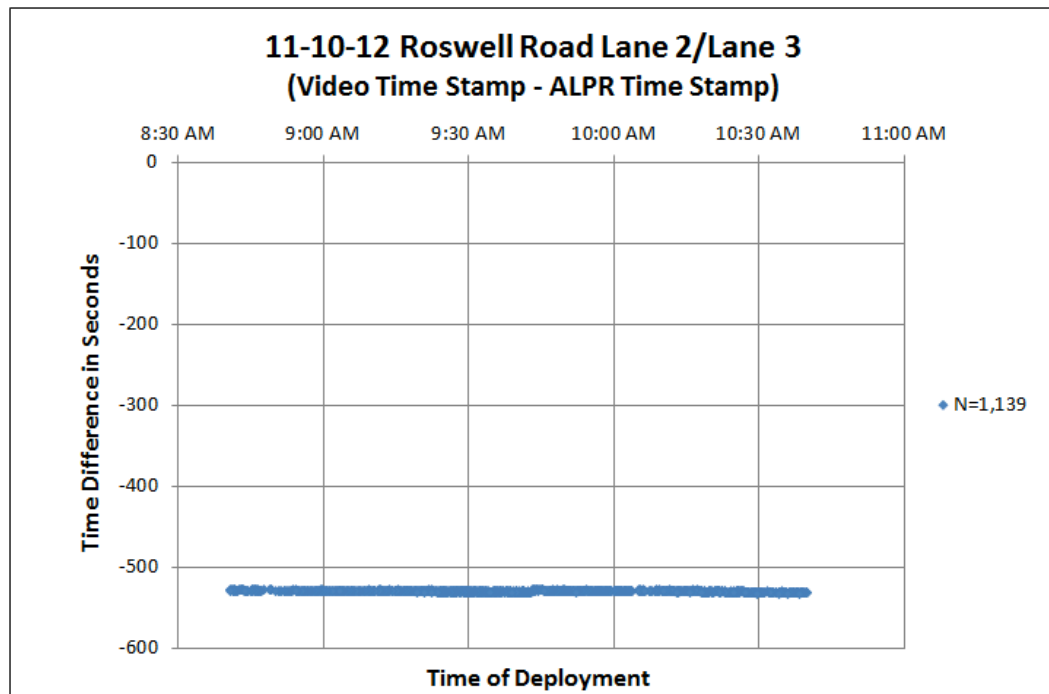
cameras whose internal times could not be corrected using the first method because they were filming lanes that had few ALPR captured vehicles. Both methods are described in more detail in the following sections.

#### 4.2.7.1 Utilizing ALPR Time Stamp Differences

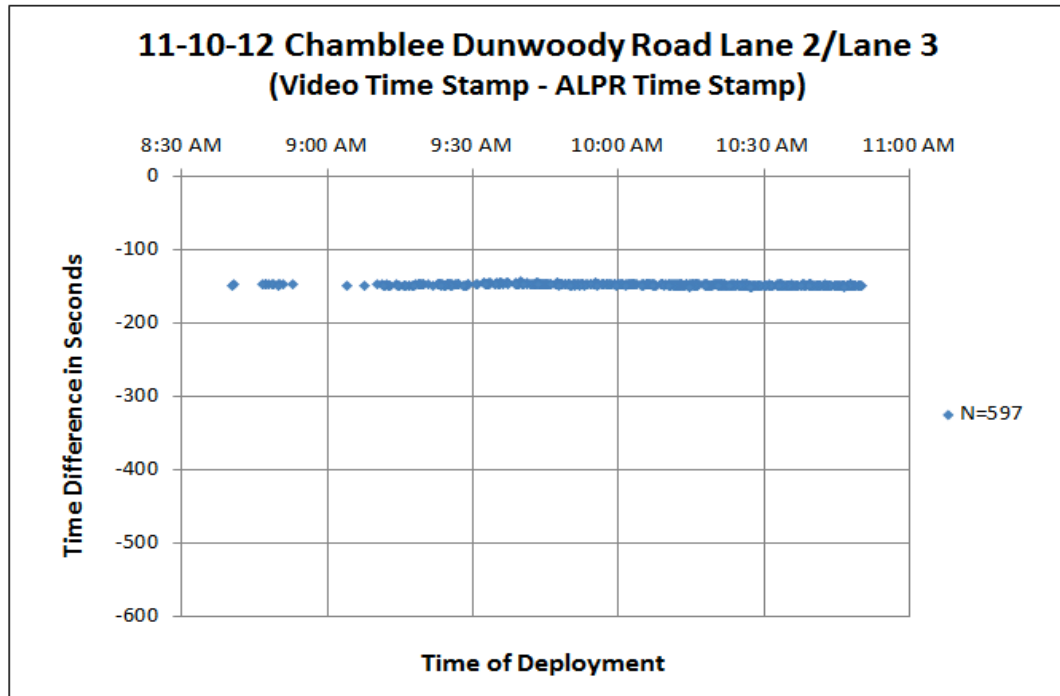
The first method for correcting the internal camera time stamps was to use the exact matches travel time algorithm to find matches between the ALPR license plate records and the video processing license plate records. (This matching was already conducted during the attempt to assign the ALPR license plate records to their freeway lane of travel.) This method works because the ALPR netbooks used at each data collection site were time-synched with each other prior to each I-285 deployment. After the license plate matching was completed, the video processing time stamps were subtracted from the ALPR time stamps to find the time difference between the ALPR time stamp and the internal camera time (video processing time stamp). The time differences calculated by this method will include the length of time it takes the vehicles to travel from the point of ALPR camera system capture to the point of video camera capture. During free flow conditions, the amount that this time difference will be off should be no more than a few seconds, but could be longer during congested conditions.

It was expected that the time differences estimated between the ALPR time stamps and the video processing time stamps would be fairly consistent across all vehicles travelling through the corridor during the data collection time period. However, minor differences of a few seconds were expected due to vehicles travelling at different speeds. Additionally, larger gradual differences over time were also expected due to gradual changes in average vehicle speed in response to varying levels of congestion over

the deployment time periods. In order to investigate the range of this time difference, the calculated time differences between the ALPR time stamps and the video processing time stamps were plotted versus time for each day, site, and camera. An example of these plots from the November 10, 2012 deployment at the Roswell Road and Chamblee Dunwoody Road sites and from the video cameras used to capture travel lanes two and three are shown in Figures 38 and 39 below.



**Figure 38: Internal video camera time correction for the lane 2/lane 3 camera at Roswell Road on November 10<sup>th</sup>, 2012**



**Figure 39: Internal video camera time correction for the lane 2/lane 3 camera at Chamblee Dunwoody Road on November 10<sup>th</sup>, 2012**

These plots from November 10, 2012 show that the internal camera time of the video camera at Roswell Road was set approximately 9 minutes behind the correct ALPR time and the internal camera time of the video camera at Chamblee Dunwoody Road was set approximately 2 minutes behind the correct ALPR time. (Thus, there would be a 7 minute error in the travel time based on the original internal camera time). Also, the plots show that throughout the deployment there was very little variation in the time difference between the ALPR license plate record time stamps and the video license plate record time stamps. This was as expected for the November 10th deployment because it took place on a Saturday in a non-work zone location under non-congested conditions. Larger ranges in the time difference between the two sets of time stamps were found for the September 7<sup>th</sup> and October 20<sup>th</sup> deployments than for the November 10<sup>th</sup> deployment.

These larger ranges were as expected due to the change in congestion conditions that occurred over the September 7<sup>th</sup> deployment period and due to the highly congested conditions present at Paces Ferry Road during the October 20<sup>th</sup> deployment period. For each of these three deployment days, the minimum time stamp difference for each camera was used to make the internal video camera time correction for each video camera. The minimum was chosen as it is the most likely to represent the time stamp difference for a vehicle travelling at free-flow speed. No attempt was made to correct for the portion of the time difference related to the vehicle travel time from the point of ALPR camera capture to the point of video camera capture as this time difference of a few seconds was insignificant relative to the overall travel times.

#### 4.2.7.2 Utilizing Weaving Vehicle Time Stamp Differences

The first method for correcting the internal video camera times often did not work for video cameras that were used to collect vehicle license plates in freeway lanes zero and one. This issue was due to the fact that the ALPR cameras miss many of the vehicles travelling in those lanes due to occlusion from vehicles travelling in the outside lanes and due to distance limitations. Using the previous method, at Northside Drive on September 7<sup>th</sup>, 2012 there was only one match between the ALPR license plate records and the video-processing license plate records for the vehicles travelling in lanes zero and one. And, on October 10<sup>th</sup>, 2012 at the Northside Drive site there were no matches between the ALPR license plate records and the video-processing license plate records for the vehicles travelling in lanes zero and one.

To investigate the necessary adjustment of the internal camera time for these cameras, efforts were made to find the same vehicles weaving between freeway lanes one

and two in both the lane zero/lane one video and the lane two/lane three video. The time into each video that the weaving vehicle was seen was recorded and then added to the start time of that video in order to create a time stamp for that vehicle in each of the two videos. Next, the time that the vehicle was seen in the lane two/lane three video was subtracted from the time that the same vehicle was seen in the lane zero/lane one video. This time difference was then added to the amount of time that the internal camera time for the lane two/lane three was calculated to be off of the actual correct time using method one. An example of this calculation from the November 10<sup>th</sup> deployment at the Northside Drive site is shown in Figure 40 below.

A	B	C	D	E	F	G	H	I
Vehicle Description	Weave Direction	L0L1 Video Start Time	L2L3 Video Start Time	L0L1 time into video	L2L3 time into video	L0L1 Camera time when seen	L2L3 Camera time when seen	camera time difference (L2L3 - L0L1)
Video 1								
Red Sedan	L2 to L1	9:38:59	9:39:37	05:51	07:54	9:44:50	9:47:31	02:41
Silver Sedan	L2 to L1			05:55	07:58	9:44:54	9:47:35	02:41
Silver Honda Civic	L2 to L1			06:15	08:18	9:45:14	9:47:55	02:41
Black Nissan SUV	L2 to L1			09:46	11:49	9:48:45	9:51:26	02:41
Gold Range Rover	L1 to L2			10:21	12:24	9:49:20	9:52:01	02:41
Video 2								
Black Toyota Sedan	L1 to L2	10:01:14	10:01:49	04:38	06:45	10:05:52	10:08:34	02:42
Silver Toyota SUV	L2 to L1			04:50	06:57	10:06:04	10:08:46	02:42
Black Hatchback	L1 to L2			05:00	07:07	10:06:14	10:08:56	02:42
Video 3								
White Dodge Truck	L1 to L2	10:23:09	10:23:50	06:22	08:22	10:29:31	10:32:12	02:41
Red Chevrolet Truck	L1 to L2			07:04	09:04	10:30:13	10:32:54	02:41
White Ford Truck	L2 to L1			07:14	09:14	10:30:23	10:33:04	02:41
		**Camera L0L1 is 2:41 slower than Camera L2L3**						

**Figure 40: Example of the spreadsheet used to conduct the second method of correcting the internal times of the video cameras**

## **4.2.8 Travel Time Analysis**

### **4.2.8.1 ALPR and Video Travel Time Analysis**

The video camera travel times and the ALPR travel times were both produced using the exact matches travel time algorithm. After the matches were produced from the travel time algorithm, the time stamp at the first site was subtracted from the time stamp at the second site to produce the travel time between the two sites. After the travel times were calculated, negative travel times were eliminated from the data set as discussed previously.

For the video camera travel time matches, one additional step was necessary to process the data. Some of the video camera travel time matches produced by the algorithm were license plate numbers that contained very few actual digits with the other “digits” containing questions marks. This resulted from the instruction to data processors to input license plate digits that they were unable to read into the video-processing program as question marks. However, license plate number matches that contain three or fewer actual digits were not considered to be reliable matches and were therefore removed from the data set.

For the ALPR travel time matches, two additional steps were necessary to process the data: removing non-plate reads and removing duplicated reads. Many of the matches produced by the exact matches algorithm are matches between ALPR records that were reads of something other than a license plate such as the words on the side of a truck. These non-plate matches were manually removed from the data set by conducting a visual assessment of the plate number records or by checking the associated infrared image when necessary. Also, because the algorithm processes plate numbers with

brackets by producing all possible plate number combinations, multiples of these plate combinations could be matched across the two site datasets for the same license plate. Duplicated matches can also occur when more than one of the three ALPR cameras captures the same license plate. These two types of duplicated matches were also manually removed from the data set by conducting a visual assessment of the plate number records.

#### 4.2.8.2 Bluetooth Travel Time Analysis

The travel times produced by the Georgia Tech custom Bluetooth and the Digiwest Bluetooth were obtained from the work produced by Stephanie Zinner for her master's thesis, which was focused on the Bluetooth aspect of the work zone testbed project. More details about the data processing methodology for the Bluetooth technologies can be found in Stephanie's master's thesis (Fall 2012) and in her Work Zone Bluetooth Technology Whitepaper [2], [13].

#### **4.2.9 Lane Bias Analysis**

An additional analysis was performed on the data collected during the October 20<sup>th</sup>, 2012 deployment to investigate potential biases in the ALPR and video travel time data resulting from uneven freeway lane distributions within the matched vehicle license plates. The lane bias analysis was performed on the October 20<sup>th</sup>, 2012 deployment because, of the six I-285 freeway deployments, this was the only deployment that took place in an active work zone and greater travel time lane biases were expected in corridors with more heavily congested traffic.



The first step in the lane bias analysis was to use the exact matches algorithm to establish freeway lane numbers for the ALPR license plate reads captured at the two data collection sites. This was accomplished by utilizing the license plate lane assignments identified using the video data. In order to maximize the number of ALPR license plate reads that were able to be assigned with their lane numbers, the corrected ALPR license plate reads created during the ALPR processing, rather than the raw ALPR license plate reads, were input into the matching algorithm along with the video-processing license plate reads. Using the corrected ALPR license plate reads instead of the raw ALPR license plate reads increased the likelihood of finding exact matches between the ALPR license plate reads and the video-processing license plate reads because they contained fewer errors, which would interfere with finding exact matches. Once data sets containing the lane numbers for the ALPR license plate records from both the Paces Ferry Road site and the Northside Drive site were established, the exact matches algorithm was used to find travel time matches between these two data sets. This produced a data set containing 107 ALPR travel time matches between the two sites with lane number information for all of the license plate records.

The original ALPR travel time analysis for the October 20<sup>th</sup>, 2012 deployment, which used the full set of raw ALPR license plate reads from the two sites as inputs to the exact matches algorithm, produced a data set containing 211 ALPR travel time matches between the two sites (without lane number information). The reduction to 107 ALPR travel time matches results from uncertain lane assignment at one or both ends of the travel time collection points. To increase the robustness of the lane bias analysis for the October 20<sup>th</sup> data, lane number were assigned to those additional vehicle matches in the

data set without lane number information using an alternative method for lane assignment. The alternative method for lane assignment involved looking up the color images from the Car System ® data associated with each of the additional ALPR matches in order to identify and record the vehicle type and color information. Next, these vehicles were located in the video files from the Paces Ferry Road and their travel lane information was recorded. Approximately 90 percent of the total matches in the data set without lane number information were able to be assigned with their corresponding lane number at the Paces Ferry Road site.

## CHAPTER 5

### RESULTS

#### *5.1 Camera Angle Configuration Test*

##### **5.1.1 ALPR Detection Rate Results**

The results of the detection rate analysis for the Spring Street camera angle configuration test are presented in Figures 41 and 42 below where they are overlaid on the diagrams showing the various camera angles that were tested during the deployment. On each of the diagrams, the orange boxes represent the first angle tested, the blue boxes represent the second angle tested, and the green boxes represent the third angle tested. In each box, the percentage represents the percentage of vehicles that were detected out of the total number of vehicles travelling in that lane during that time period, which is the number within the parentheses. Vehicles with a temporary license plate, vehicles with no license plate, and motorcycles were removed from the total passing vehicle counts because these types of plates were not expected to be detected by the ALPR equipment. These vehicles accounted for about 1.5 percent of the total vehicles passing the site during this deployment.

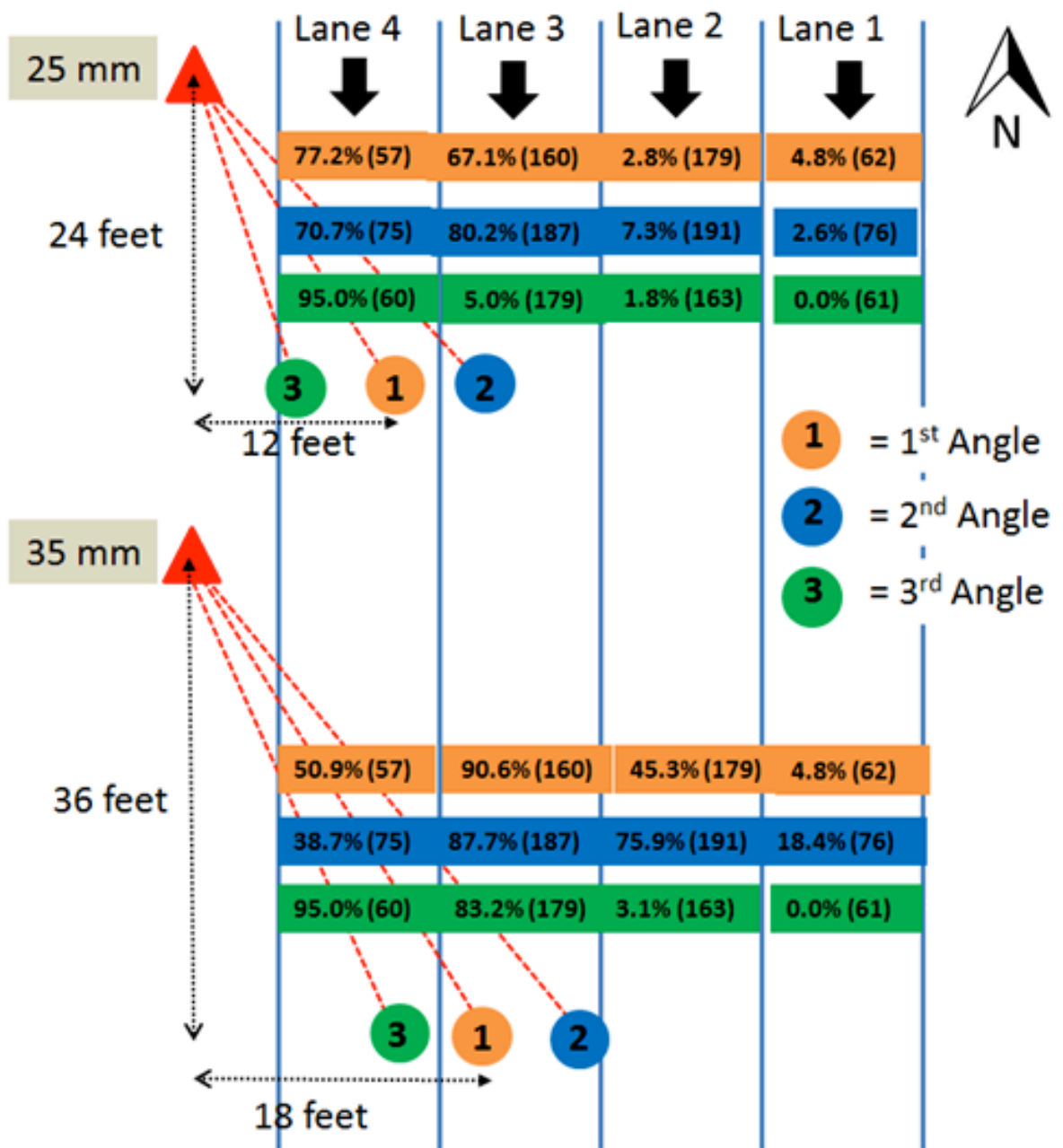
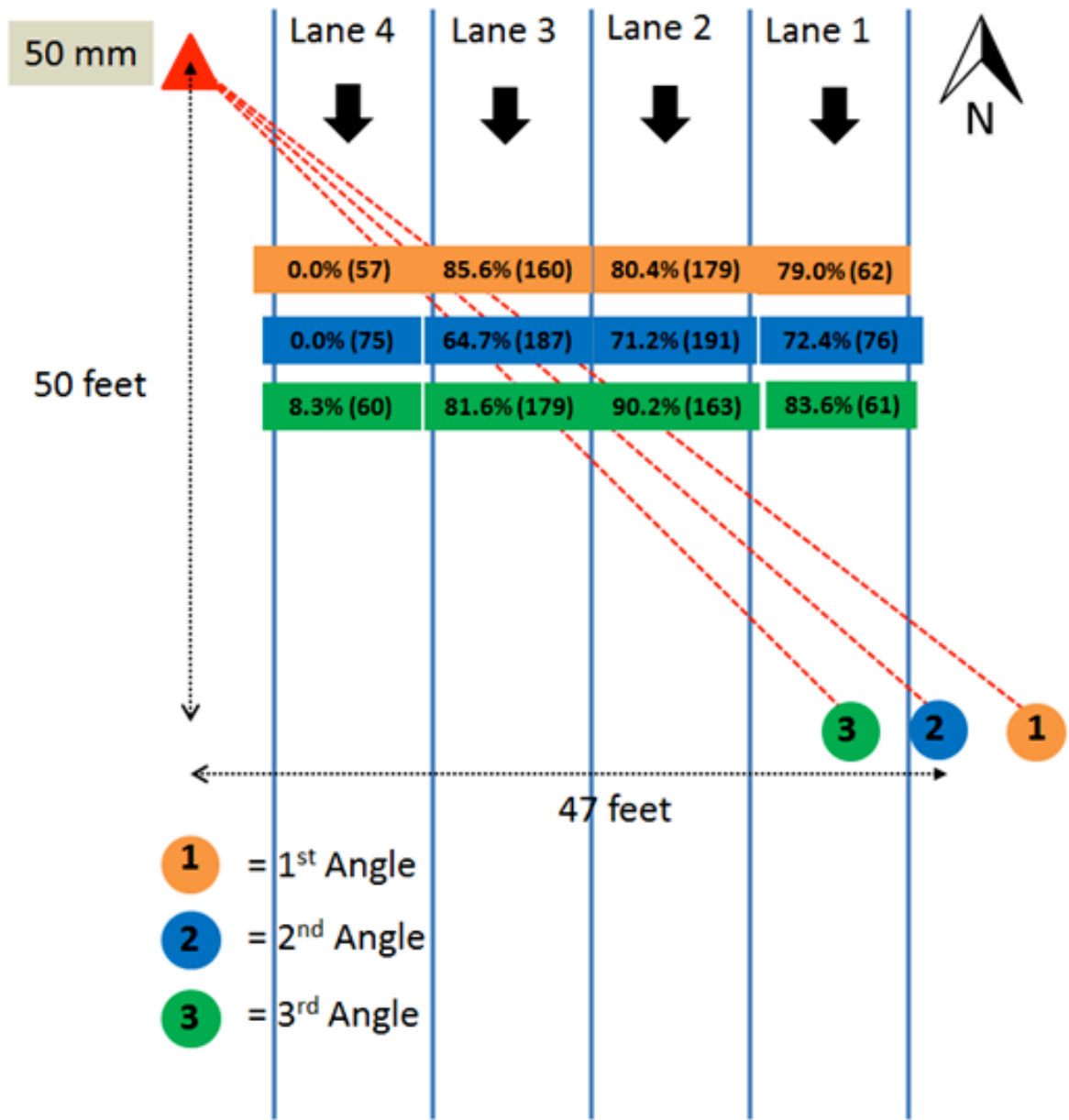


Figure 41: Schematic of the 25mm and 35mm camera detection rates per angle and per lane from the camera angle configuration test.



**Figure 42: Schematic of the 50mm camera detection rates per angle and per lane from the camera angle configuration test**

The results indicate that the 25mm camera is best suited for detecting vehicles travelling in the closest lanes, which in this deployment were lanes 3 and 4. The results also show that, for the 25mm camera, the recommended camera angle produced the

highest detection rate average over both lanes 3 and 4. The results indicate that the 35mm camera is best suited for capturing vehicles travelling in the closest and the middle lanes, which in this deployment were lanes 2-4. The results also show that, for the 35mm camera, the third angle produced the highest detection rates averaged over two lanes (lanes 3 and 4). It is interesting that higher detection rates averaged over lanes 3 and 4 were achieved by the 35mm camera rather than the 25mm camera, which is specifically designed to capture the closest lanes. However, if the 35mm camera were to be used specifically to capture vehicles travelling in the middle two lanes, the recommended camera angle is shown to perform the best. For the 50mm camera, the results show that it is best suited for capturing vehicles travelling in the outside two lanes (lanes 1 and 2), and the highest detections rates for these two lanes were achieved using the third camera angle.

One issue with using Spring Street as the deployment location for this test was that this corridor has 10 foot wide lanes rather than 12 foot wide lanes. It is possible that the recommended camera angles are for corridors with the more standard 12 foot wide lanes, which would bias the camera angle results. This bias would manifest itself to the greatest extent in the 50mm camera test because this camera captures vehicles travelling in the furthest lanes where the difference in roadway width would be the greatest. If this test were performed on a corridor with 12 foot lane widths, it is possible that the recommended camera angle could produce the best detection rates results for the 50mm camera.

#### 5.1.1.1 Detection Rate Bootstrap Analysis

Additionally, a bootstrap statistical test was utilized to establish confidence bounds around the detected and undetected vehicle percentages achieved by each camera for each combination of travel lane and camera angle. The bootstrap method was chosen to establish the confidence bounds because of its ability to account for influences of potential outliers and small data sets on the calculation of the mean [14]. For this analysis, the bootstrap method was used to re-sample the detection rate data for each camera, travel lane, and camera angle combination. To re-sample the data, the detection rates were split into two categories, the number of detected vehicles and the number of undetected vehicles, and a script was written to re-sample this data 1000 times. Finally, the 1000 samples were placed in numerical order and the 25<sup>th</sup> ranked sample, the 975<sup>th</sup> ranked sample and the mean were used to produce the confidence bounds.

The results of the detection rate bootstrap analysis are shown in Figures 43 and 44 below with the results for lanes 1 and 2 in Figure 43 and the results for lanes 3 and 4 in Figure 44. These results confirm that the camera angle is critical to achieving high license plate detection rates with detection rates varying by a wide margin when the angle is changed by less than five degrees. The results show that optimal camera and angle combinations can reasonably achieve 90 percent detection rates in environments with conditions similar to the Spring Street corridor.

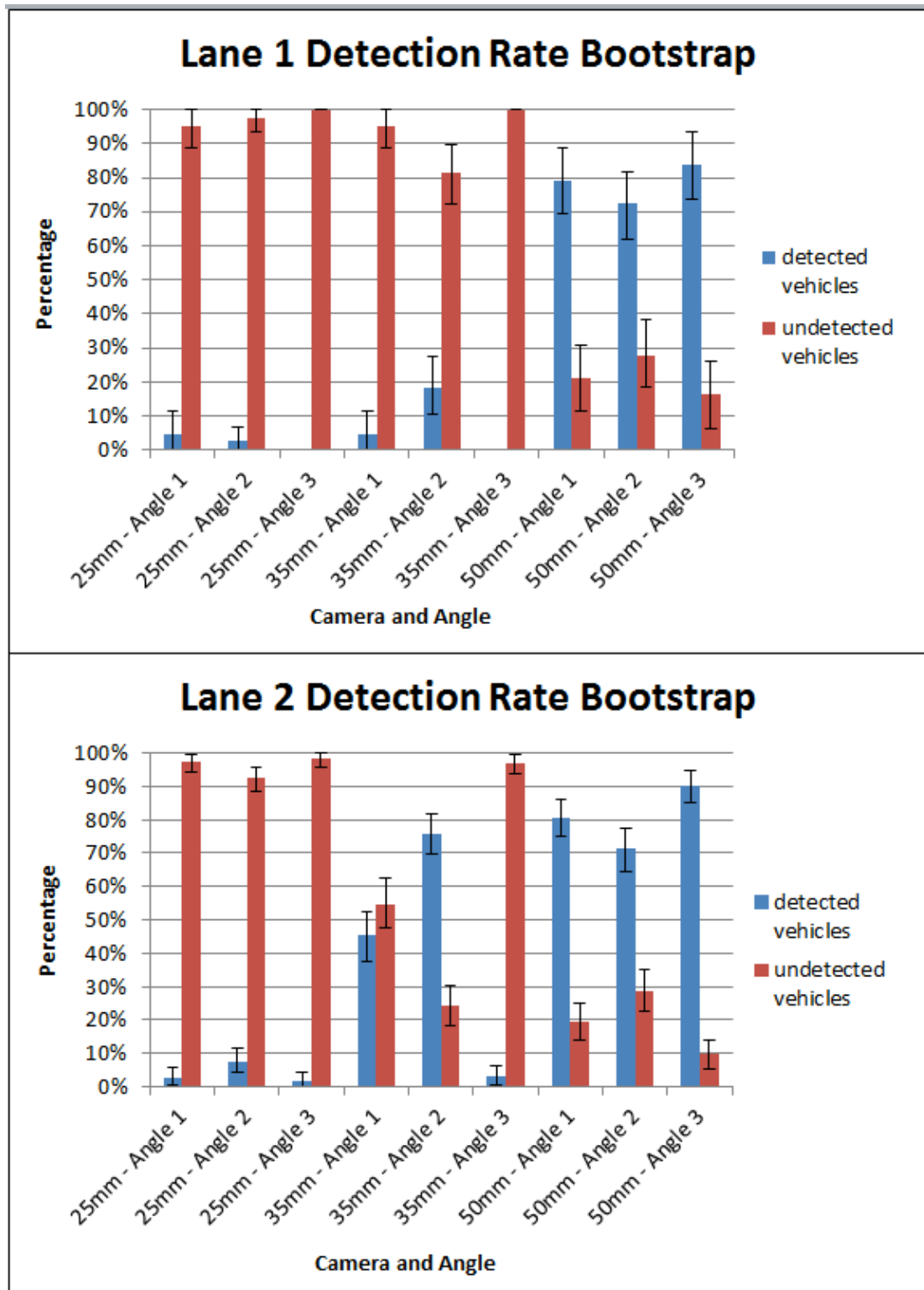


Figure 43: Results of the detection rate bootstrap analysis for lane 1 and lane 2



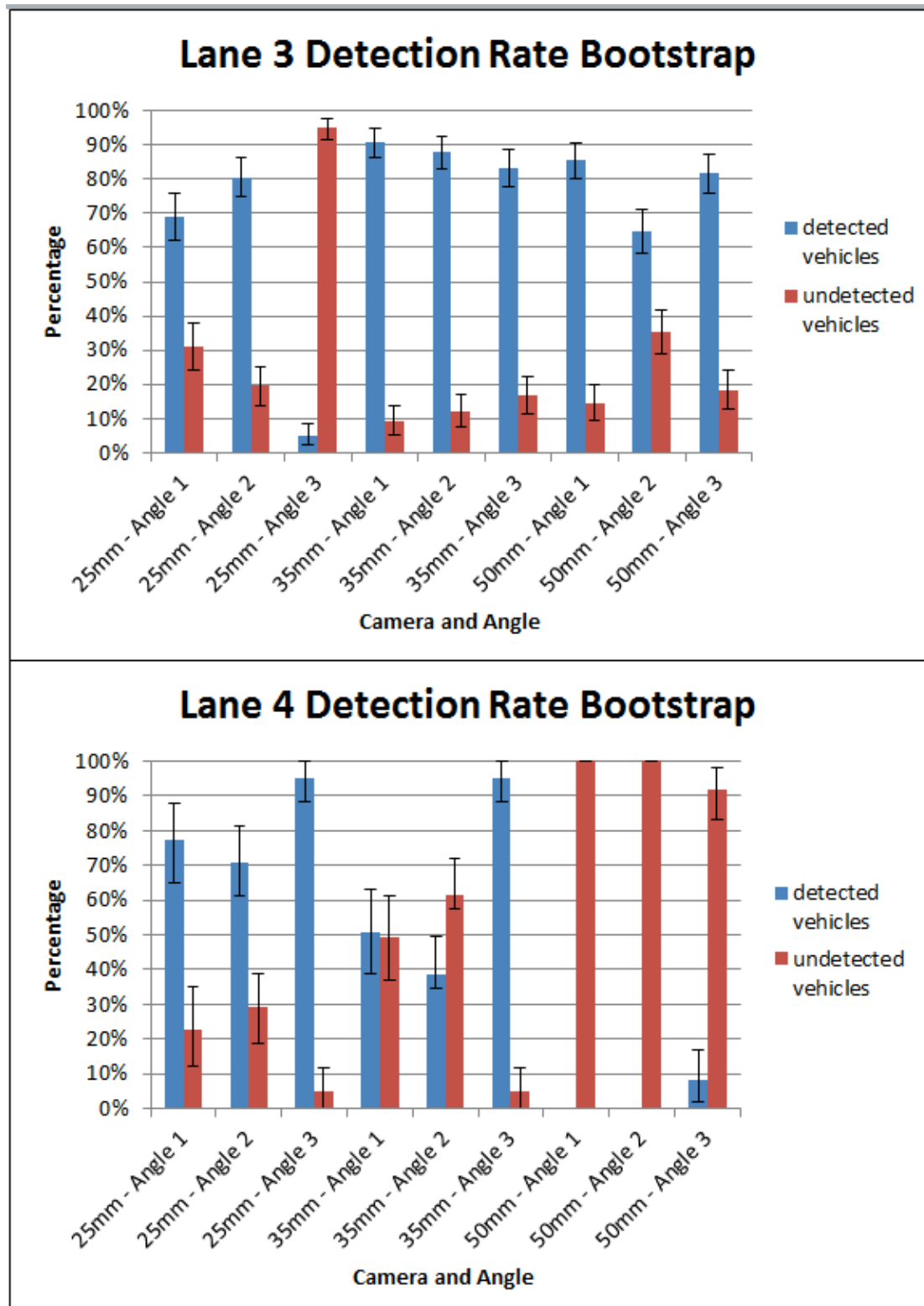
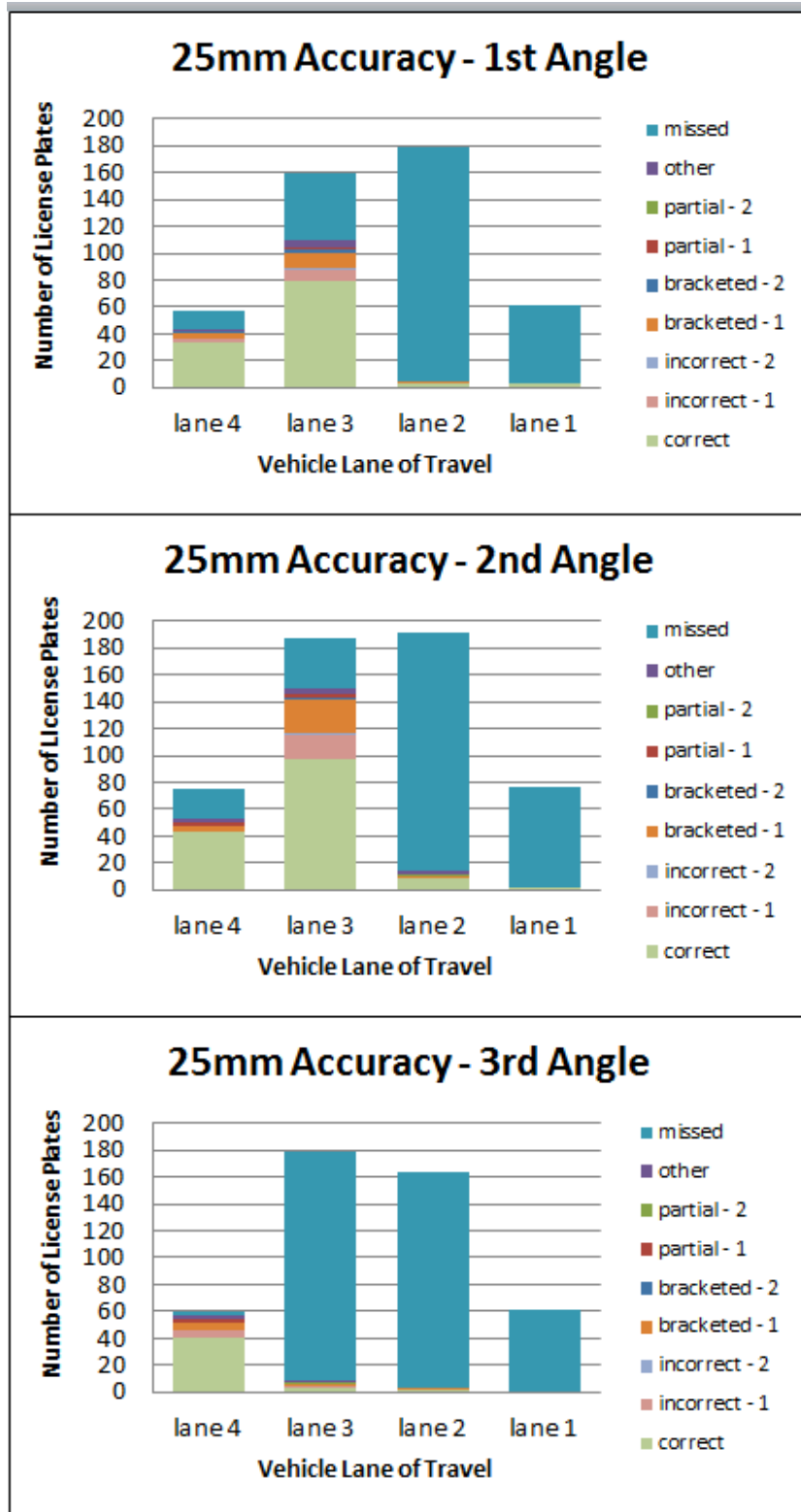


Figure 44: Results of the detection rate bootstrap analysis for lane 3 and lane 4

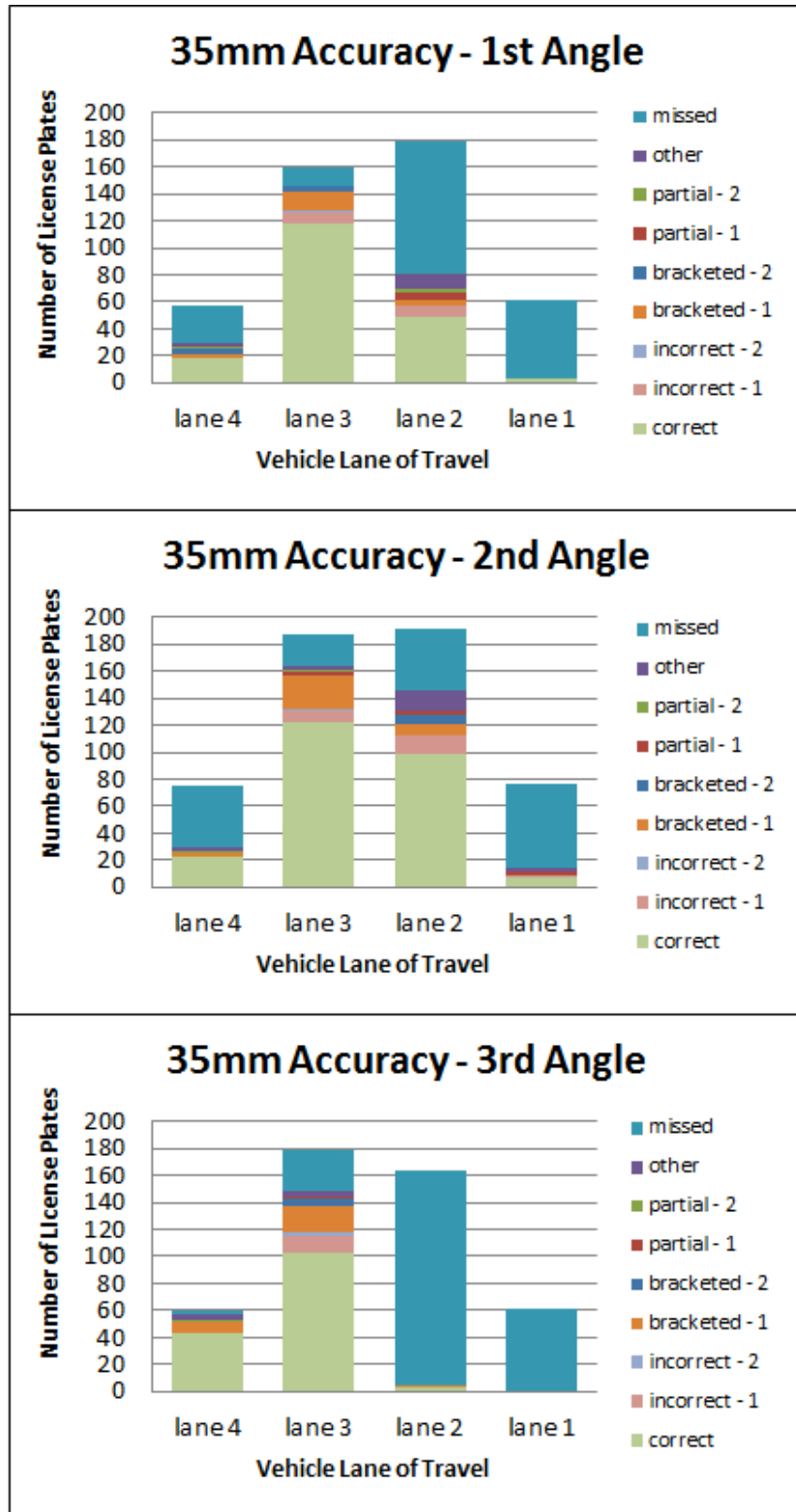
### **5.1.2 ALPR Accuracy Results**

The results of the accuracy analysis for the Spring Street camera angle configuration test are shown in Figures 45-47 below. The accuracy results for each of the three cameras are separated into three figures with the results for each of the three camera angles further separated into three graphs. Each graph shows the number of license plate reads for each of the four travel lanes that fell into the categories of correct, incorrect-1, incorrect-2, bracketed-1, bracketed-2, partial-1, partial-2, other, and missed. The “other” category describes license plate reads that contained a combination of the other errors or contained more than two instances of one error. An explanation of the other accuracy categories was previously presented in section 4.1.5.

The 25mm camera achieved the best detection rates for lanes 3 and 4 using the recommended camera angle (2<sup>nd</sup> angle). The results of the accuracy analysis show that during the 2<sup>nd</sup> angle time period, the 25mm camera detected and correctly read the license plates of about 60 percent of the vehicles in lane 4 and about 50 percent of the vehicles in lane 3. The 35mm camera achieved the best detection rates for lanes 3 and 4 using the 3<sup>rd</sup> camera angle. The results of the accuracy analysis show that during the 3<sup>rd</sup> angle time period, the 35mm camera detected and correctly read the license plates of about 70 percent of the vehicles in lane 4 and about 60 percent of the vehicles in lane 3. The 50mm camera achieved the best detection rates for lanes 1 and 2 using the 3<sup>rd</sup> camera angle. The results of the accuracy analysis show that during the 3<sup>rd</sup> angle time period, the 50mm camera detected and correctly read the license plates of about 75 percent of the vehicles in lane 2 and about 70 percent of the vehicles in lane 1.



**Figure 45: Accuracy assessment results from the camera angle configuration test for the 25mm camera**



**Figure 46: Accuracy assessment results from the camera angle configuration test for the 35mm camera**

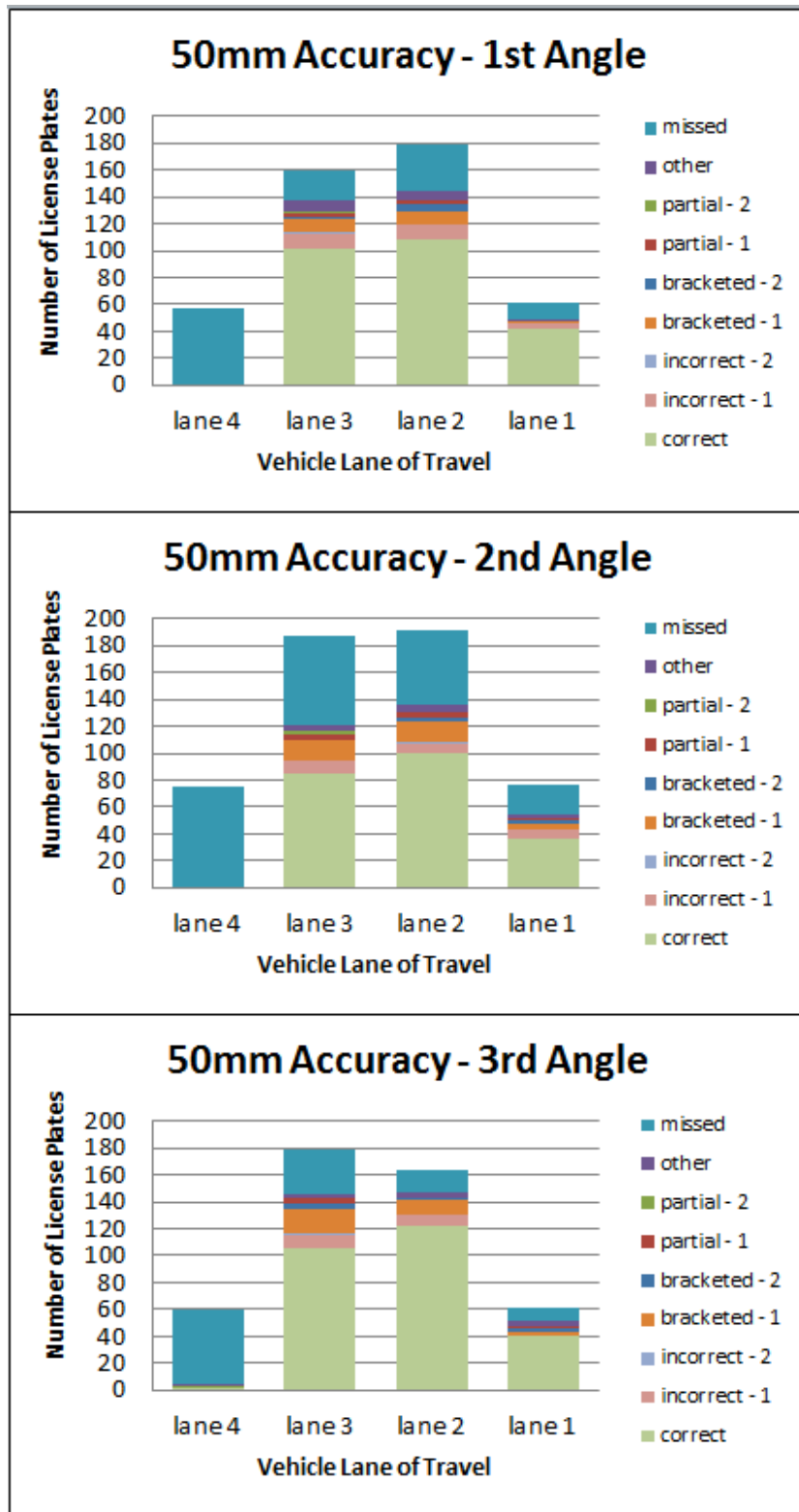


Figure 47: Accuracy assessment results from the camera angle configuration test for the 50mm camera

#### 5.1.2.1 Accuracy Bootstrap Analysis

The bootstrap method was utilized again to establish confidence bounds around the means for the number of ALPR vehicle license plate reads that fell into each of the accuracy categories. For the bootstrap analysis, the accuracy categories were simplified into only four categories: correct, 1-wrong, 2-wrong, and 3+ wrong. These categories describe whether a license plate was read completely correctly or with a certain number of digits wrong. To prepare for the bootstrap analysis, the number of license plate reads falling into each of these categories for each of the camera, lane, and camera angle combinations were calculated. Then, for each camera, lane, and camera angle combination, these numbers were input into a script that generated 1000 re-samples of the data. Finally, the results from the 1000 re-samples were numerically ranked and the 25<sup>th</sup> ranked value, the 975<sup>th</sup> ranked value, and the mean were used to establish the confidence bounds. The accuracy bootstrap analysis does not include missed license plates and should therefore be interpreted as showing that if a plate is detected, the accuracy is within the given bounds.

The results of the accuracy bootstrap analysis are shown in Figures 48-50 below where the results for each of the three cameras are separated into individual figures and the results for each of the four lanes are separated into individual graphs. Accuracy bootstrap results for camera, lane, and angle combinations with fewer than 30 samples are not shown because the sample size is too small to establish meaningful confidence bounds around those accuracies. These results show that the camera angle is still important in achieving high accuracy percentages for detected vehicles and that once a

license plate is detected, it can be reasonably expected that the plate will be correctly read about 70 percent of the time.

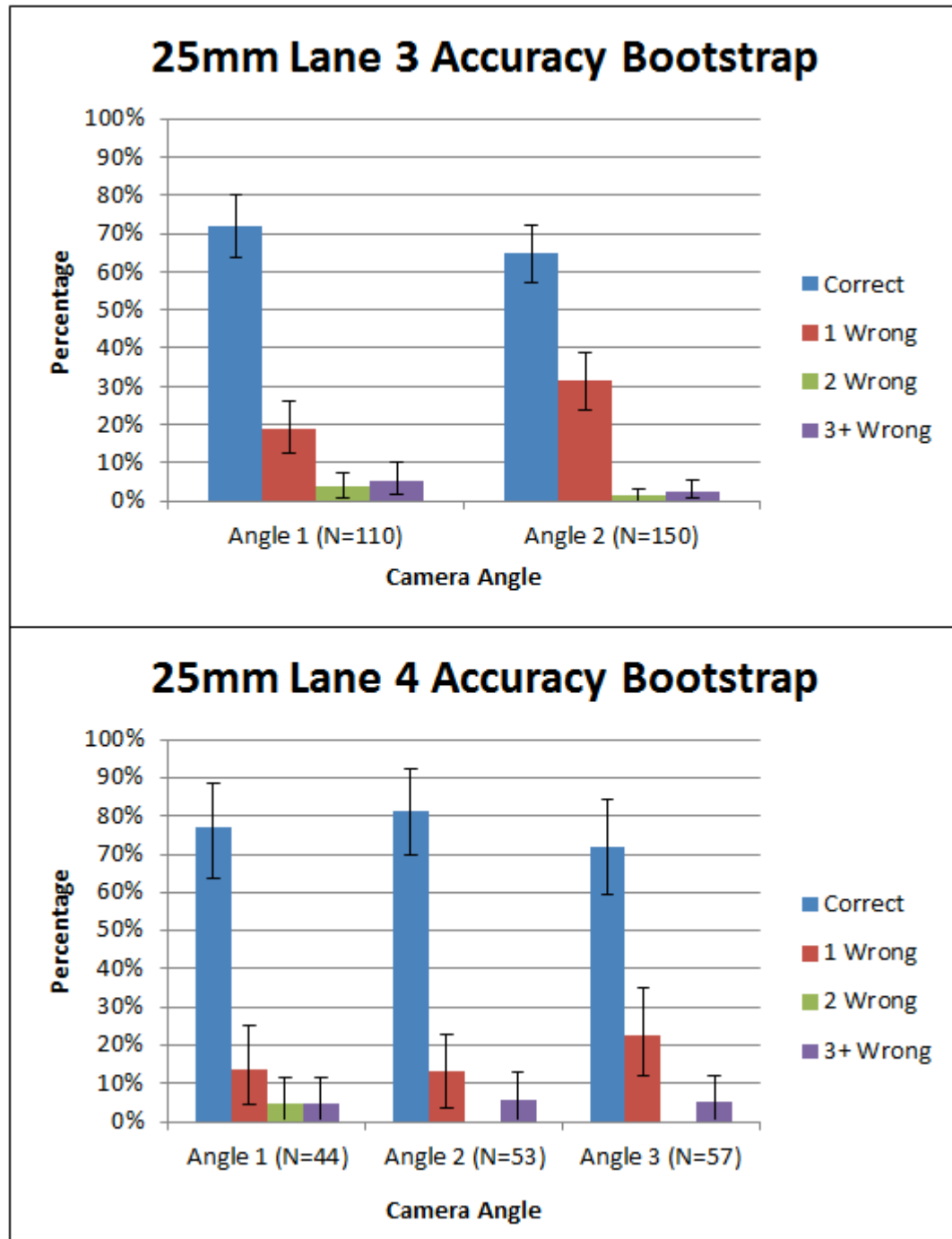


Figure 48: Results of the accuracy bootstrap analysis for the 25mm camera

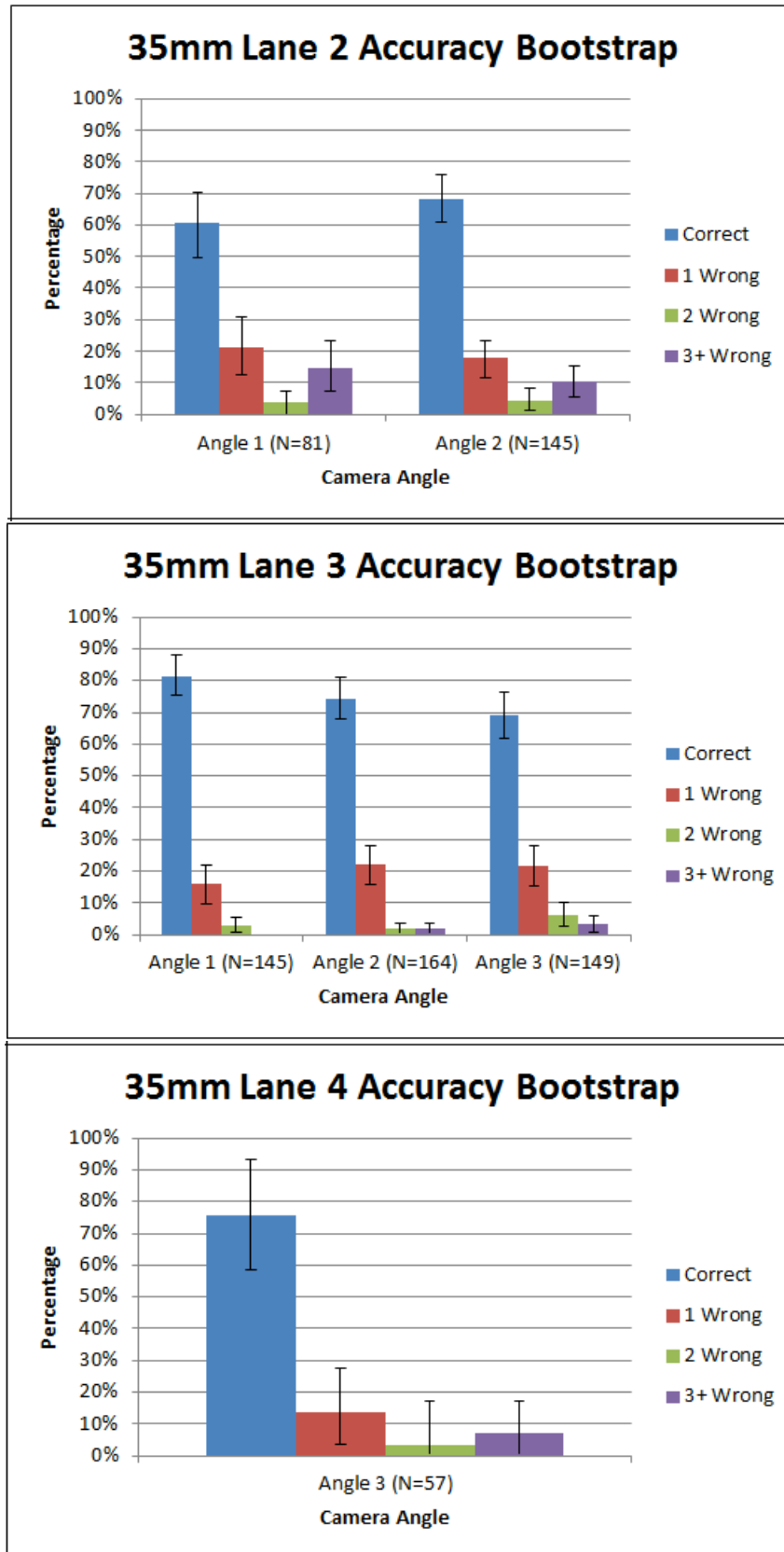


Figure 49: Results of the accuracy bootstrap analysis for the 35mm camera



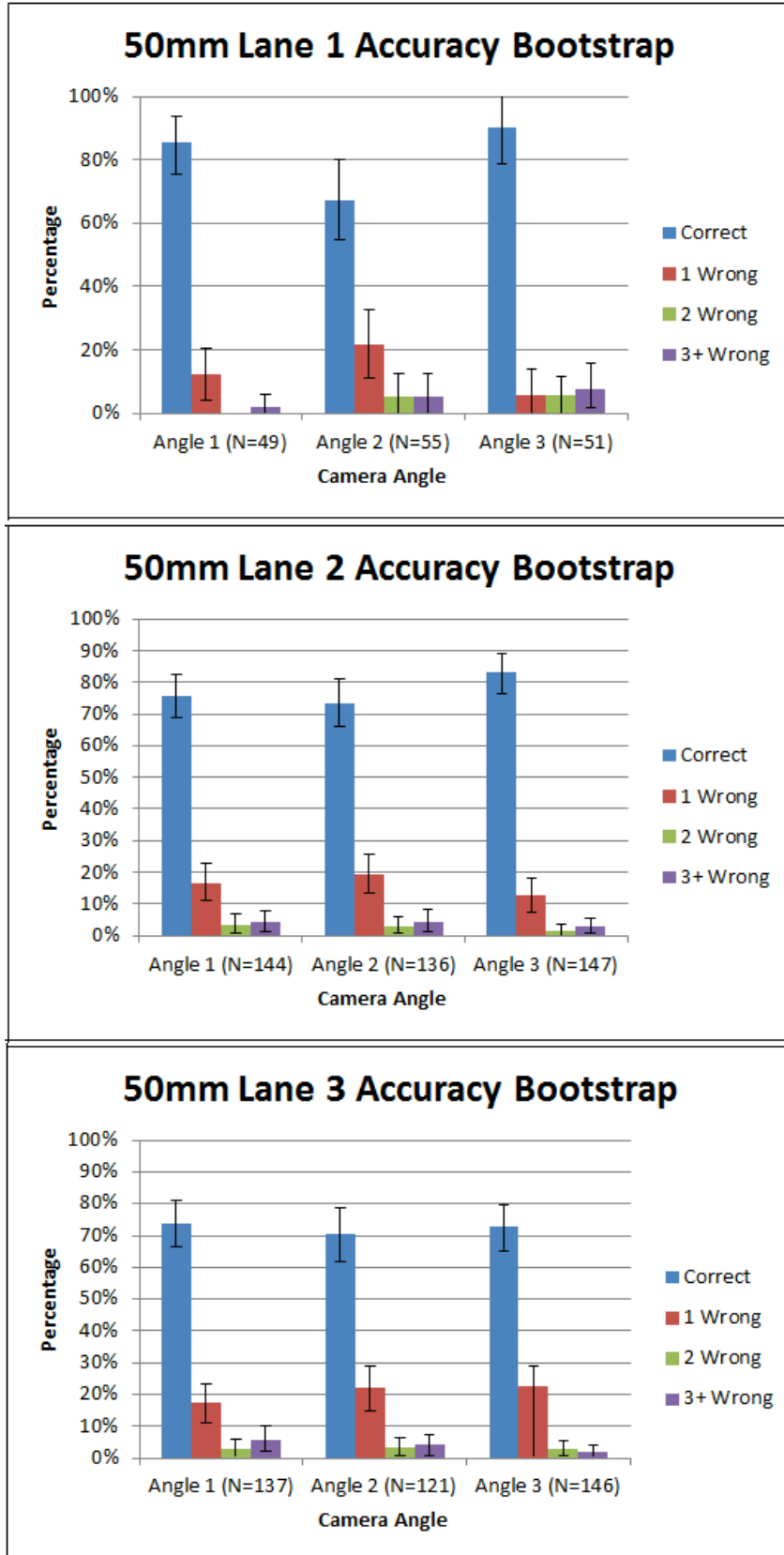


Figure 50: Results of the accuracy bootstrap analysis for the 50mm camera

## *5.2 I-285 Freeway Deployments*

As was mentioned previously, I-285 data from only the Friday, September 7<sup>th</sup>, 2012, Saturday, October 20<sup>th</sup>, 2012, Saturday, and November 10<sup>th</sup>, 2012 deployments were processed. Friday, September 7<sup>th</sup> was chosen because this data was collected during the weekday morning peak period and the data therefore reflects a transition from congestion during the peak period to free-flow conditions after the end of the peak period. Saturday, October 20<sup>th</sup> was chosen because this data was collected during active work zone conditions during which heavy congestion was captured at the Paces Ferry Road site and free-flow conditions were captured at the Northside Drive site. Saturday, November 10<sup>th</sup> was chosen because Digiwest Bluetooth data was collected during that deployment and therefore a comparison between the video data, ALPR data, custom Bluetooth data, and Digiwest Bluetooth data was possible for that day.

### **5.2.1 ALPR System Detection Rate Results**

The results of the ALPR detection rate analysis from the I-285 freeway deployments are presented in Table 2 below. For each site, the table shows the total number of vehicles that passed the site and the total number of raw ALPR license plate reads that were collected at that site. The next four columns in the table show the four categories that the ALPR reads could fall into: non-plate reads, unclear reads, duplicate reads, and unique reads, which were previously described in section 4.2.5 of this thesis. The ALPR detection rate is calculated by dividing the number of unique ALPR plate reads collected at a site by the total number of vehicles that passed that site. The table also shows the number of ALPR travel time pairs that were matched using the exact matches travel time algorithm for each of the three deployments.

**Table 2: Number of license plates in each detection rate category from the September 7<sup>th</sup>, 2012, October 20<sup>th</sup>, 2012, and November 10<sup>th</sup>, 2012 deployments**

Day/Site	Total Vehicle Count from Video	# of Raw ALPR Reads	Non-Plate ALPR Reads	Unclear ALPR Reads	Duplicate ALPR Plate Reads	Unique ALPR Plate Reads	ALPR Detection Rate	ALPR Exact Matches
Sept. 7 – Paces Ferry Rd.	9,303	8,176	1,608	223	2,474	3,871	41.6%	131
Sept. 7 – Northside Dr.	15,828	7,404	1,390	100	2,257	3,657	23.1%	
Oct. 20 – Paces Ferry Rd.	5,098	4,920	1,192	18	553	3,157	61.9%	211
Oct. 20 – Northside Dr.	5,823	2,882	583	19	617	1,663	28.6%	
Nov. 10 – Chamblee Dunwoody Rd.	9,780	3,893	387	91	1,353	2,062	21.1%	326
Nov. 10 – Roswell Rd.	8,615	4,927	282	209	1,375	3,061	35.5%	

The results show that the highest detection rate was achieved at the Paces Ferry Site during the October, 20<sup>th</sup>, 2012 deployment at about 60 percent detection. The other five detection rates range from about 20 percent up to about 40 percent detection. These detection rates are significantly lower than those achieved during the Spring Street camera angle configuration test. However, there are several factors related to the I-285 freeway deployments that could have influenced the lower detection rates that were achieved at each of these sites during these deployments. These factors include: the increased distance between the edge of the roadway and the camera set-up location, the increased chances for vehicle occlusion due to congestion and a larger number of travel lanes, the increased width of the roadway, improper camera angle set-up, and non-optimal camera height set-up causing partial interference from guardrails in the camera views. Additionally, some of the variation in the percentage of travel time pairs that were able to be matched by the exact matches algorithm could be attributed to differences in the number of vehicles lost to I-75 between the Paces Ferry Road and the Northside

Drive sites and the number of vehicles lost to the GA-400 interchange between the Chamblee Dunwoody Road and Roswell Road sites.

### **5.2.2 Travel Time Analysis Results**

Travel time plots were generated to compare the travel times produced by the various technologies and to investigate trends over time and over various levels of congestion. The travel time plots were developed in three stages: a plot including negative travel time matches, a plot excluding negative travel time matches, and a plot excluding negative travel time matches and travel time outliers. Negative travel time matches can result from incorrect matches (not the same vehicle) or from a vehicle travelling through the corridor more than once where it is detected at the second site the first time it passes through and at the first site the second time it passes through. These negative travel times do not represent actual travel times and were therefore removed as the first step in cleaning the travel time data.

Travel time outliers can occur when drivers make a stop during their trip through the corridor, which results in matches with longer travel times than would have been experienced had the drivers driven continuously through the corridor. This type of outlier can occur in the video, ALPR, and Bluetooth data. Outliers can also result when the travel time algorithm matches license plate records that are not actually the same vehicle. This type of outlier can only occur in the video and ALPR data. Analysis of the data showed that the first cause of outliers is much more common than the second.

Outliers were removed from each data set by computing a fifteen minute rolling average travel time and removing any travel times that were greater than two standard deviations away from this average travel time. The primary reason for the removal of

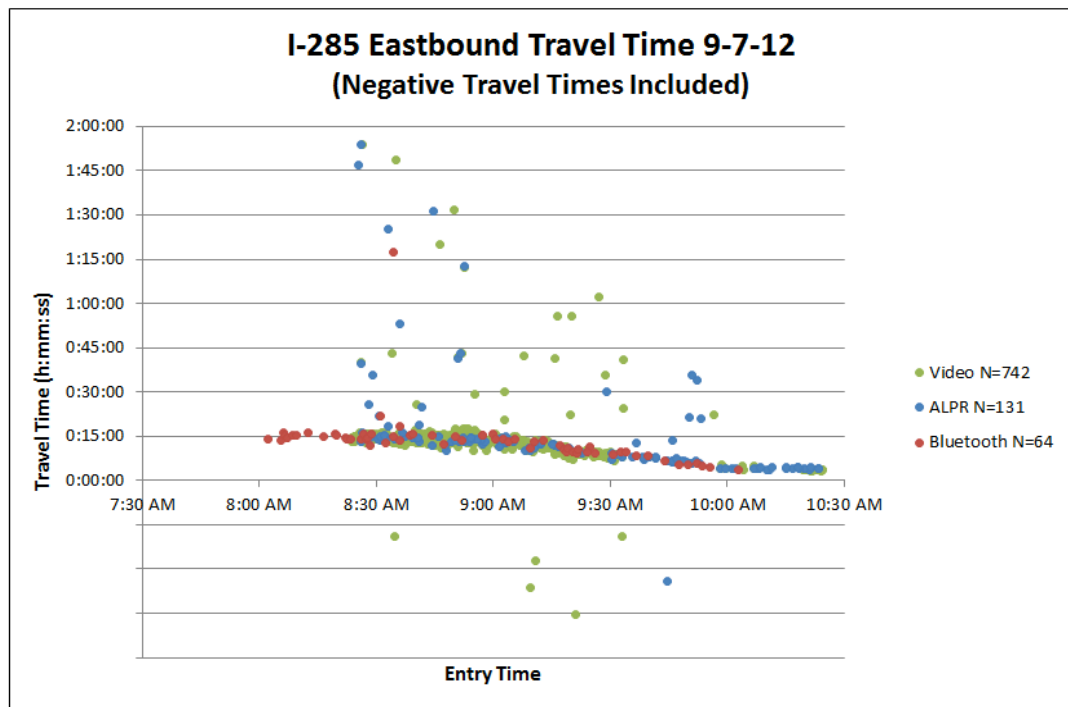
outliers was to enable an accurate comparison of the travel times produced by each of the technologies through the construction of y-y plots. The third travel time plot for each of the deployments shows the travel times with both the negative travel times and the outlier travel times removed.

#### 5.2.2.1 Friday, September 7<sup>th</sup>, 2012

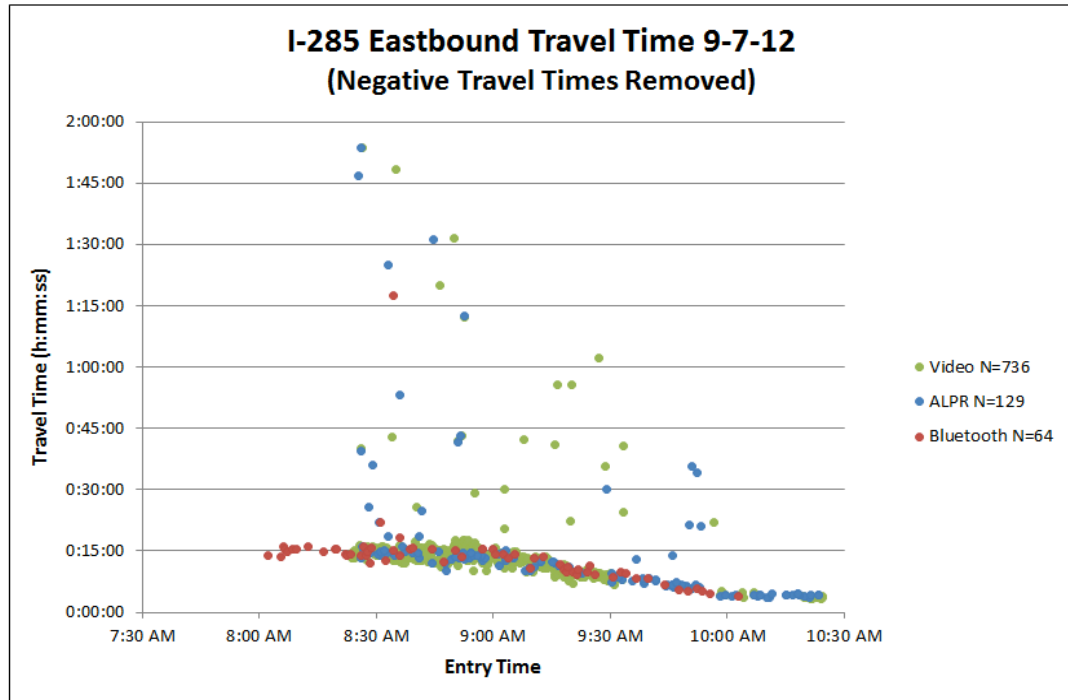
The September 7<sup>th</sup>, 2012 data collection deployment took place on a Friday morning during non-work zone conditions in the corridor from Paces Ferry Road to Northside Drive. The travel time results from the Friday, September 7<sup>th</sup>, 2012 deployment for the video, ALPR, and custom Bluetooth units are shown in Figures 51-53 below. From the first plot to the second plot, six video travel time data points and two ALPR travel time data points were removed from the data because they represented negative travel times. From the second plot to the third plot, 21 video travel time data points and 13 ALPR travel time data points were removed from the data because they were identified as travel time outliers. In the travel time plot with outlier travel times removed (Figure 53), the range of the y-axis has been reduced in order to better show changes in the travel times over the time of the deployment and to better compare the travel times produced by each technology.

Additionally, two ALPR data points have been highlighted with a red box in Figure 53 because these data points are considered travel time outliers, but were not removed from the data set using the outlier removal method that was previously described. These two data points were unable to be removed using this outlier removal method because, for this deployment, there were limited ALPR travel time matches resulting in the failure of the two-standard deviation rule to capture these outliers. Also,

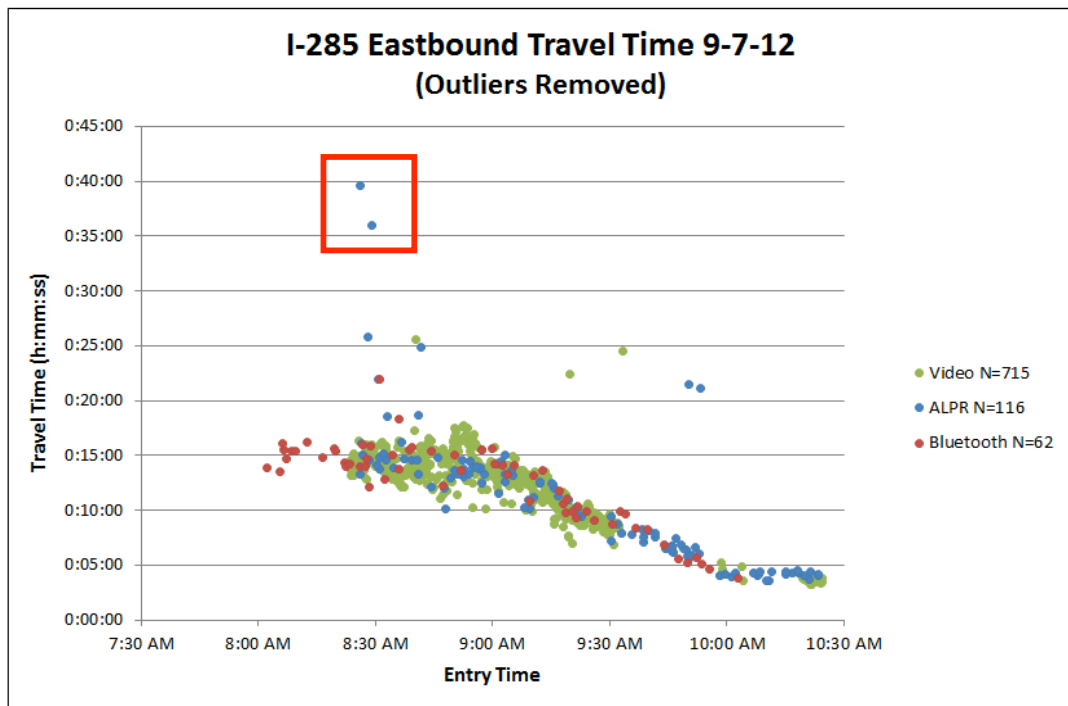
because these data points occur at the very beginning of the ALPR data where there is no prior travel time baseline for comparison. The issues causing the non-removal of outliers would not occur in longer-term real-world data collection efforts because, after the initial build-up period, there would always be prior data to compare against. The two-standard deviation rule provided a simple filtering rule, but future efforts will need to consider more robust filtering schemes. These two ALPR outlier data points were included in the travel time plot in Figure 53, but were removed from the data set prior to the creation of the comparison y-y plots (shown below in Figure 54) so as not to introduce undue bias into the comparison.



**Figure 51: Video, ALPR, and Custom Bluetooth travel times from September 7<sup>th</sup>, 2012 including the negative travel time matches**



**Figure 52: Video, ALPR, and Custom Bluetooth travel times from September 7<sup>th</sup>, 2012 excluding the negative travel time matches**



**Figure 53: Video, ALPR, and Custom Bluetooth travel times from September 7<sup>th</sup>, 2012 excluding the negative travel time matches and the outliers**

From the travel time plot in Figure 57, a decreasing trend in the travel time can be seen over the course of the deployment. This trend is attributed to the trailing off of the morning peak period as the deployment time moved from around 8:00 AM to about 10:30 AM. Some significant congestion was present in the corridor near the beginning of the deployment, which then tapered off into free-flow conditions a little before 10:00 AM. Although significant congestion was present during the beginning of this data collection period, the congestion was not as severe as was present during the October 20<sup>th</sup>, 2012 and April 13<sup>th</sup>, 2012 work zone deployments, which are discussed in subsequent sections of this chapter.

Additionally, this travel time plot shows that the video, ALPR, and custom Bluetooth units seem to be producing comparable travel times over the course of the deployment period, which is confirmed in the comparison y-y plots shown in Figure 58 below. These y-y plots separately compare the travel times produced by the three types of equipment. These y-y plots were produced by plotting the average travel times produced by each technology over five minute bins. The R-squared values of 0.92, 0.9, and 0.86 on these plots show that, for this deployment, the technologies were producing comparable estimates of the vehicle travel times with the ALPR and Bluetooth travel times slightly more comparable to the video travel times than they were to each other. Best fit lines were added to these y-y plots because the September 7<sup>th</sup> data collected period covered various congestion levels, which allowed for a comparison of the travel time results across various congestion conditions. These y-y plots show that during lightly-congested and non-congested conditions there is very little bias in the travel times



produced by any of the vehicle detection technologies, and therefore, any could be reliably used to communicate travel times to motorists during these conditions.

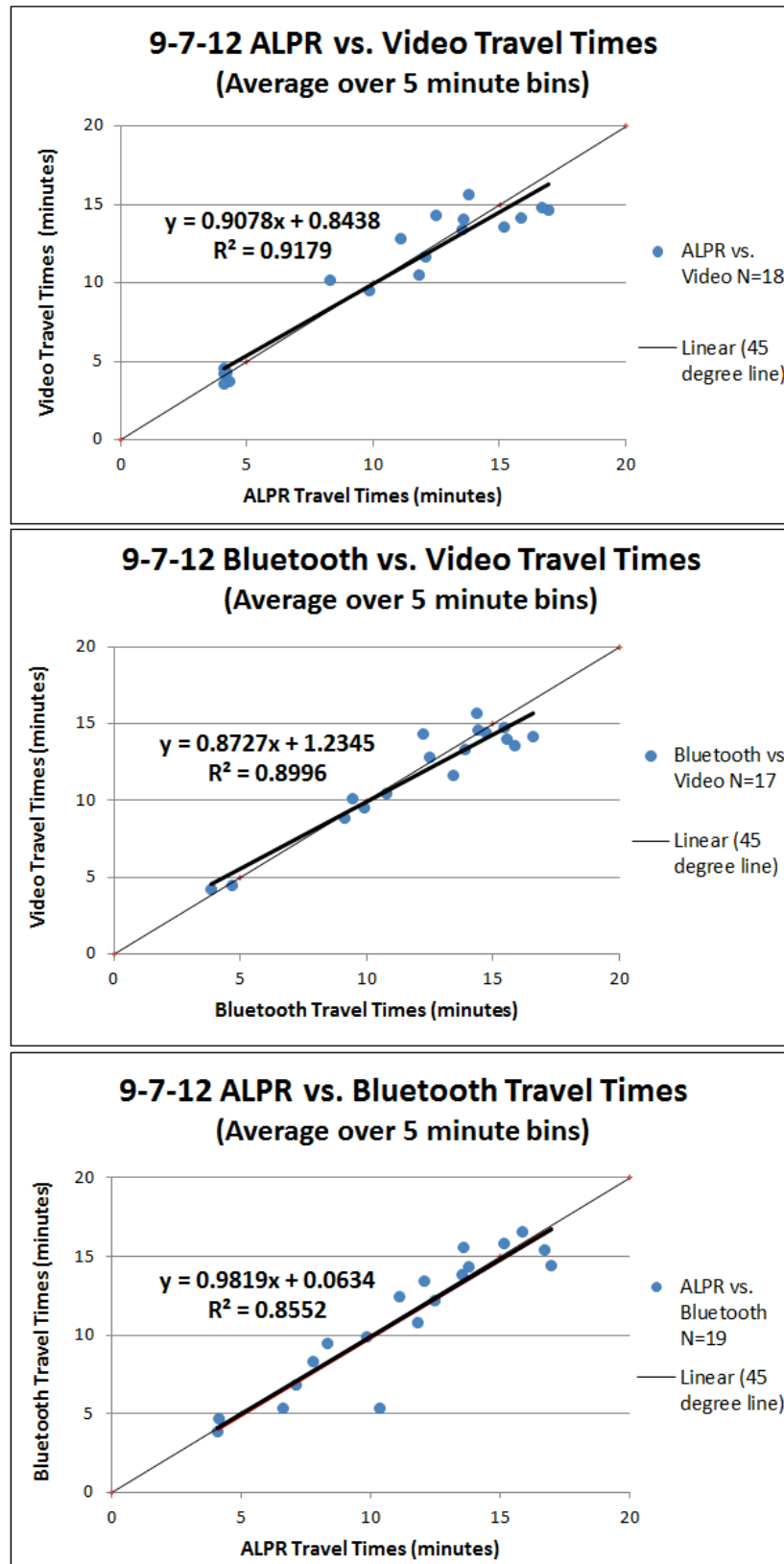
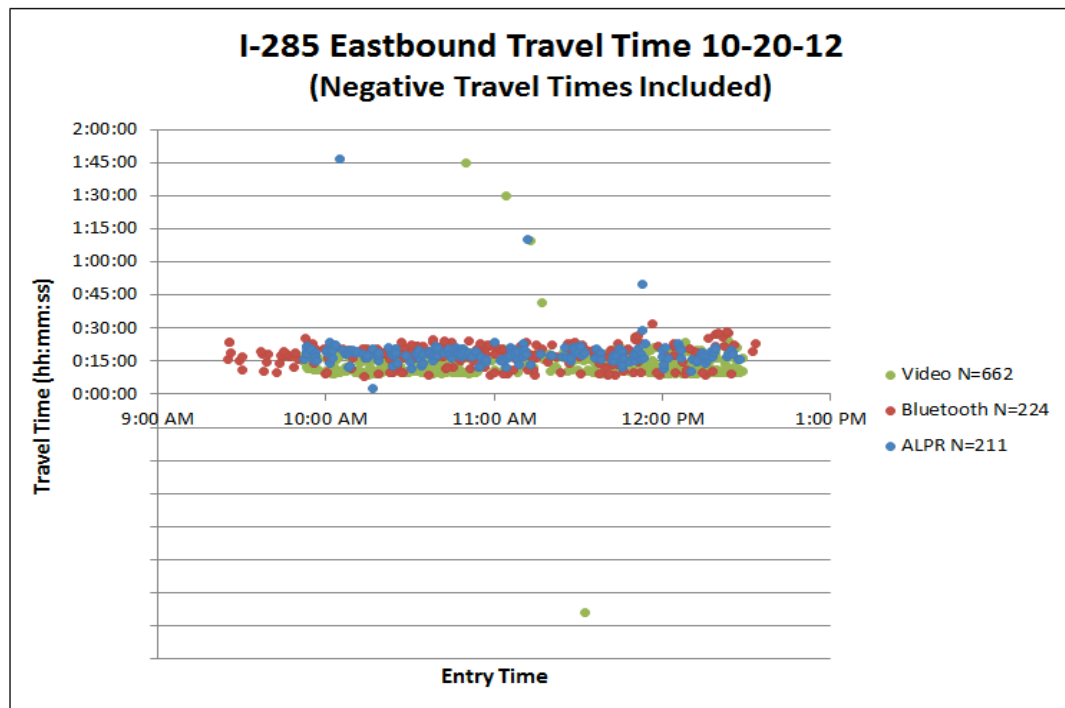


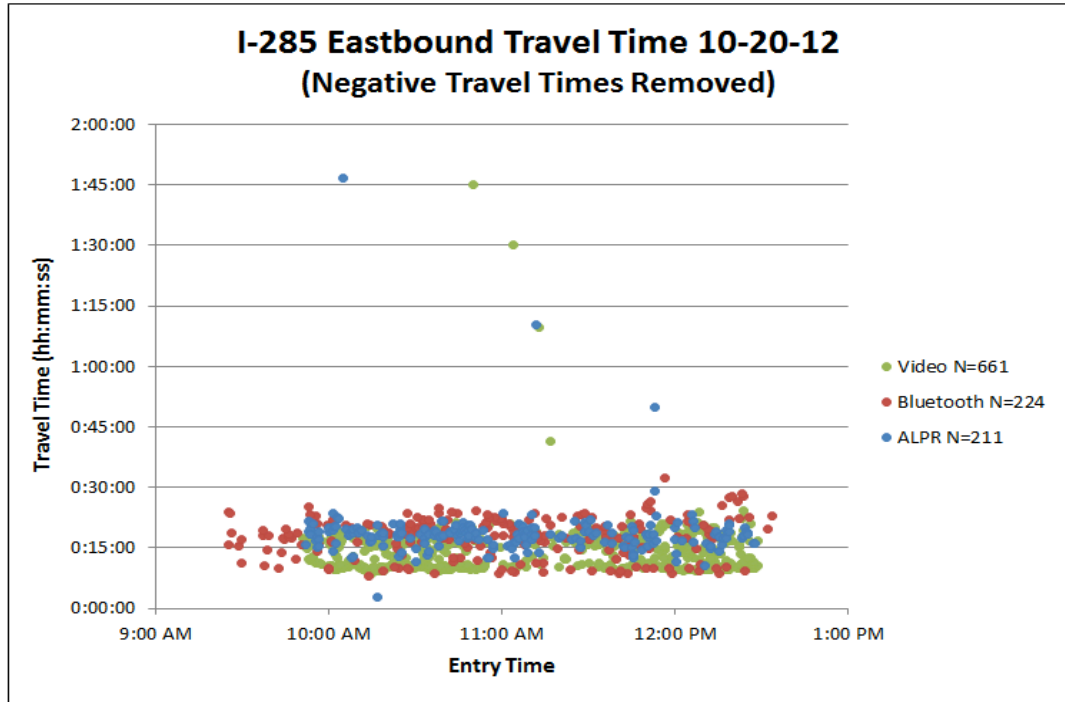
Figure 54: Comparison y-y plots for technologies deployed on September 7<sup>th</sup>, 2012

### 5.2.2.2 Saturday, October 20<sup>th</sup>, 2012

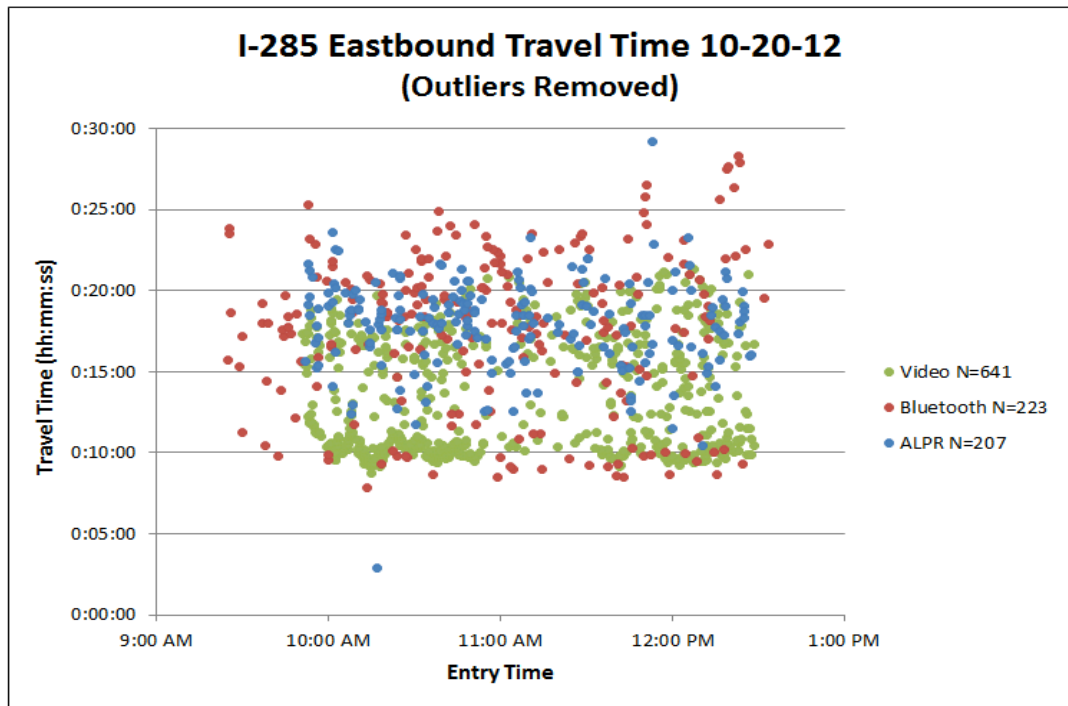
The October 20<sup>th</sup>, 2012 data collection deployment was conducted on a Saturday morning in the corridor from Paces Ferry Road to Northside Drive during active work zone conditions. The series of three travel time plots from this deployment for the video, ALPR, and custom Bluetooth units are shown in Figures 55-57 below. From the first plot to the second plot, one video travel time data point was removed from the data because it represented a negative travel time. From the second plot to the third plot, 20 video, one Bluetooth, and four ALPR travel time data points were removed because they were identified as outliers. Note that, after the outliers were removed, the range of the y-axis has again been reduced on the third plot so as to better show the range of the travel times and to more easily compare the travel times produced by the different technologies.



**Figure 55: Video, ALPR, and Custom Bluetooth travel times from October 20<sup>th</sup>, 2012 including the negative travel time matches**



**Figure 56: Video, ALPR, and Custom Bluetooth travel times from October 20<sup>th</sup>, 2012 excluding the negative travel time matches**



**Figure 57: Video, ALPR, and Custom Bluetooth travel times from October 20<sup>th</sup>, 2012 excluding the negative travel time matches and the outliers**

From the plot in Figure 57, it can be seen that the majority of the travel times typically ranged from approximately 8 minutes to 25 minutes over the course of the deployment period. By looking more closely at the data, two separate bands of travel times can be seen in the video travel times – one around a 10 minute travel time and one around a 17 minute travel time. One possible explanation for the development of these two separate travel time bands from the video data could be the presence of distinct travel time differences across the various freeway travel lanes. The work zone lane closure for this corridor was a one mile stretch of the leftmost inside lane of the freeway. Therefore, it is possible that vehicles merging into the right (outside) lanes from the left (inside) lanes at the point of lane closure caused the left lanes of the freeway to move faster than the right lanes due to the increased back-up in the right lanes.

Further emphasis is added to the lane bias theory by the fact that, in the Figure 57 travel time plot, the average ALPR travel time appears to be hovering around a larger value than the average video travel time. The ALPR travel times appear to be more in line with the higher band of video travel times. This is likely due to the ALPR cameras detecting more of the vehicles travelling in the slower (outside) lanes of the freeway. This is as would be expected for the ALPR cameras because vehicle occlusion and longer sight distances are likely to prevent the cameras from capturing many of the license plates of vehicles in the farther away inside freeway lanes. A more in-depth investigation of the existence and implications of lane biases in the travel time results from this deployment is presented in section 5.2.3 of this thesis.

Additionally, the travel time plot in Figure 57 also shows that the custom Bluetooth devices appear to be detecting vehicles in both of the travel time bands with a

larger proportion of the Bluetooth travel times falling into the higher travel time band. This indicates that the Bluetooth devices may also have a bias towards the slower moving vehicles, but for different reasons than why the ALPR cameras may have a bias towards these vehicles. For the Bluetooth units, this bias may be a result of slower moving vehicles remaining in the Bluetooth detection zone for longer lengths of time than the faster moving vehicles, which gives these slower moving vehicles a higher chance of being detected by the Bluetooth devices.

Lane bias could also be present in the travel times produced by the license plate video processing. Even though all of the license plate video cameras were placed on freeway overpasses with the same view of all travel lanes, a lane bias may exist in the travel times from this data as more tractor trailer trucks travel in the outside lanes of the freeway than in the inside lanes. Due to their height, tractor trailer trucks can sometimes block the license plates of vehicles in front of them from the camera view especially if they are following closely behind the vehicles as is the case during congested conditions. This means that during the video processing a greater percentage of the vehicles in the outside lanes could be having their license plate numbers input as “misses” into the program because they are blocked from view. The result is that the video processing travel times may be biased towards the faster moving left lanes because there is a higher likelihood of finding license plate matches for the vehicles in these lanes from the video processing data sets.

Y-y plots comparing the travel times produced by the video, ALPR, and Bluetooth technologies during this deployment are presented in Figure 58 below with one plot comparing each pair of technologies. Again, these y-y plots were produced by

plotting the average travel times produced by each technology over the same five minute bin periods. The y-y plots for the October 20<sup>th</sup> data do not show the linear regression best fit lines and the associated r-squared values for the data because only one traffic flow condition was present during this deployment and a range of traffic flow conditions are required to show a more meaningful relationship between the travel times produced by the various devices.

The ALPR vs. video and the Bluetooth vs. video y-y plots show that the ALPR and the Bluetooth devices both produce slower travel times on average than those produced by the video license plate processing. The ALPR vs. Bluetooth y-y plot shows that these two devices tend to produce travel times that are more in sync with each other than with the video license plate processing travel times. It is difficult to distinguish between how much of the ALPR and Bluetooth bias is attributed to them detecting more slower moving vehicles and how much is attributed to the video processing's bias towards faster moving vehicles. If the ALPR and the Bluetooth devices are biased towards slower moving vehicles, this may not be a fatal flaw when communicating work zone travel times to motorists as drivers are not likely to become upset by experiencing a faster travel time than was communicated to them. However, it is likely that the ALPR devices are biased towards the travel times of the vehicles in the lanes adjacent to their set up location. This means that the ALPR travel times could have been biased towards the faster moving vehicles if the systems had been set up in the median of the freeway rather than the roadside. It would be more troubling to have the devices biased towards producing faster travel times because many motorists are likely to get upset about experiencing slower travel times than they were communicated.

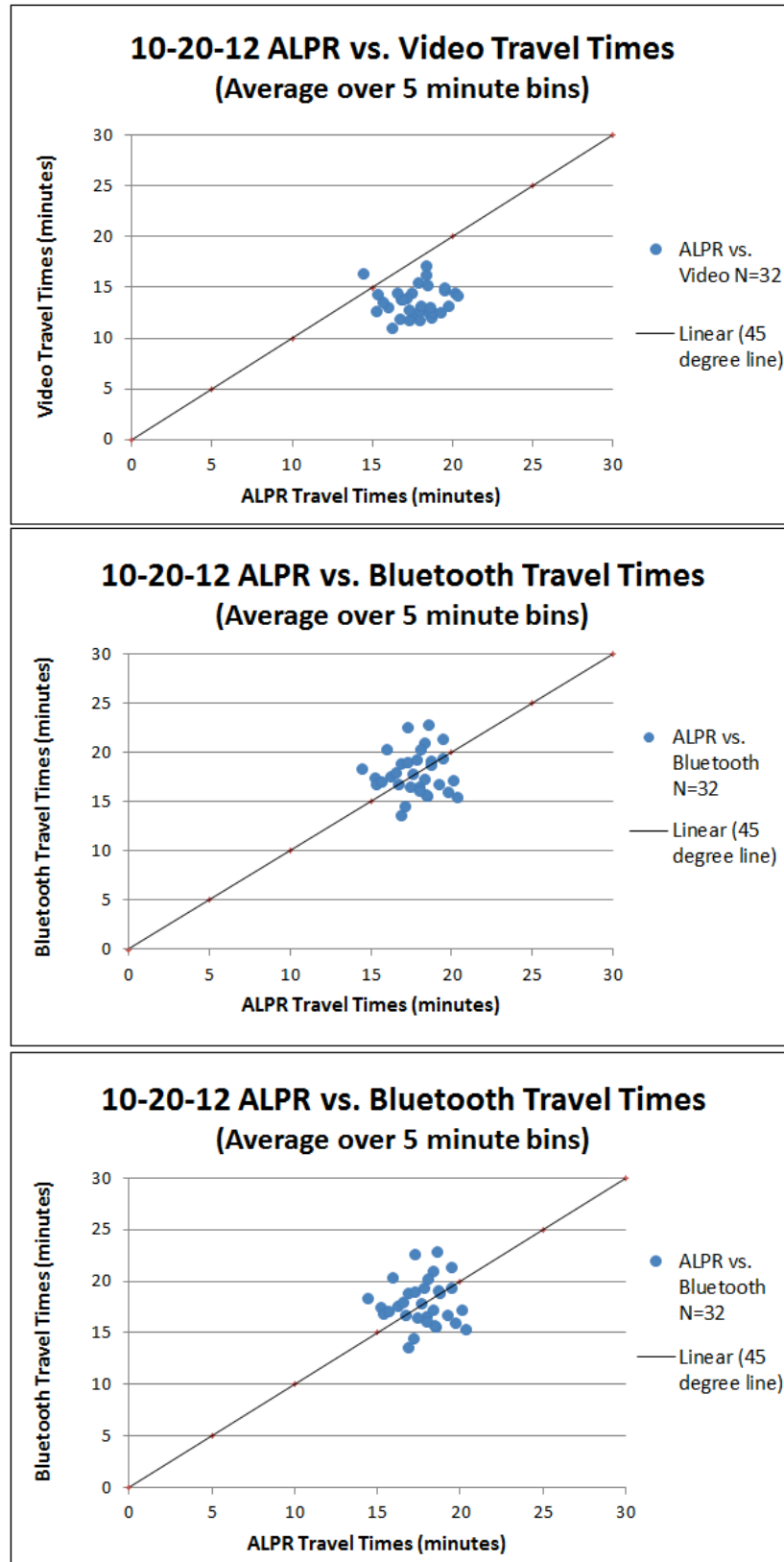


Figure 58: Comparison y-y plots for the technologies deployed on October 20<sup>th</sup>, 2012



#### 5.2.2.3 Saturday, November 10<sup>th</sup>, 2012

The November 10<sup>th</sup>, 2012 deployment was conducted on a Saturday morning during non-work zone conditions in the corridor from Chamblee Dunwoody Road to Roswell Road. The series of three travel time plots from this deployment for the video, ALPR, Digiwest Bluetooth, and custom Bluetooth technologies are shown below in Figures 59-61. From the first plot to the second plot, one video and two ALPR travel time data points were removed from the data because they represented negative travel times. From the second plot to the third plot, thirty-six video, eight ALPR, one Digiwest Bluetooth, and two custom Bluetooth travel time data points were removed from the data because they were identified as outliers during the outlier identification process. As with the previous travel time results, the third travel time plot with the outliers removed has a reduced range on the y-axis in order to better observe trends and differences in the travel time results.

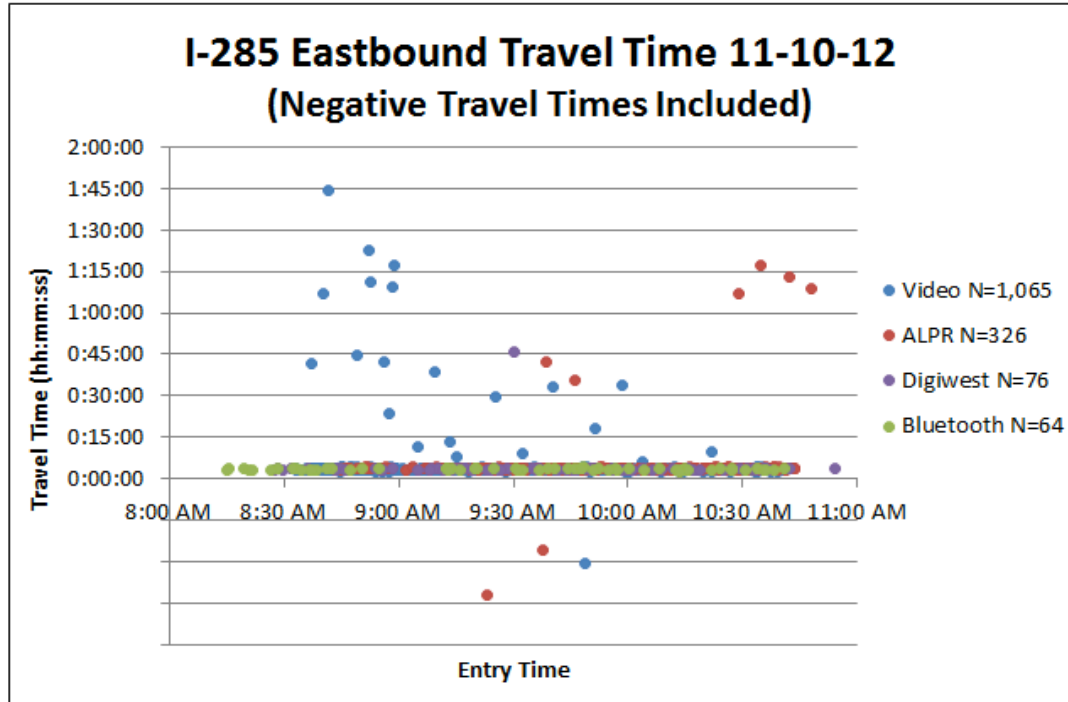


Figure 59: Video, ALPR, Digiwest Bluetooth, and Custom Bluetooth travel times from November 10<sup>th</sup>, 2012 including the negative travel time matches

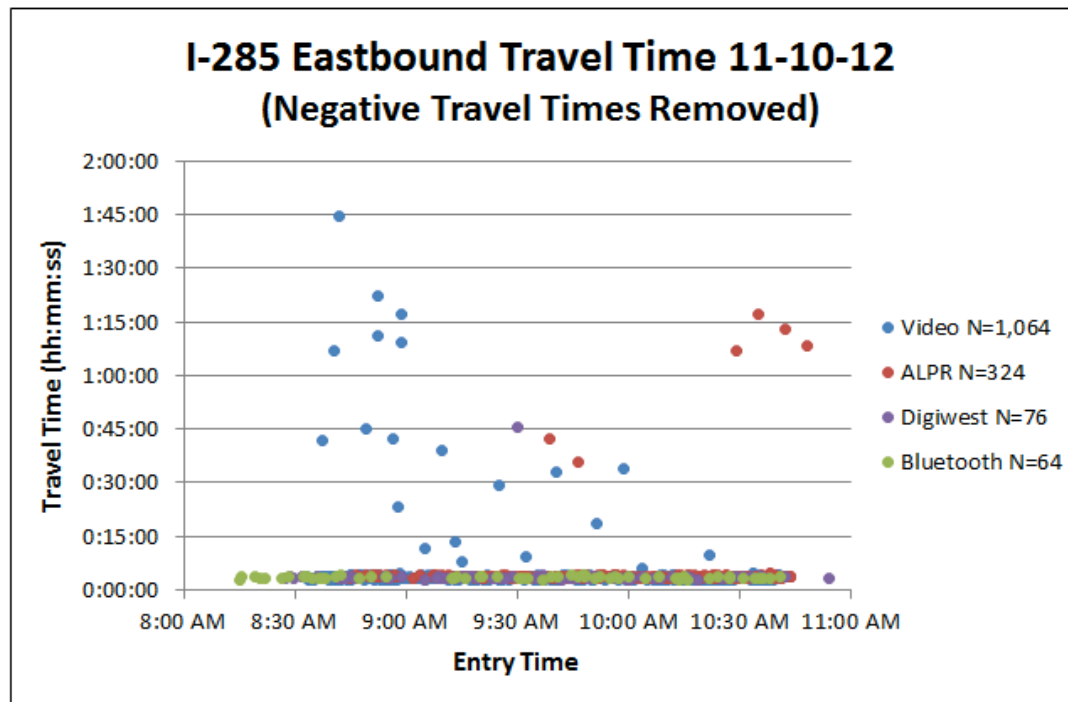
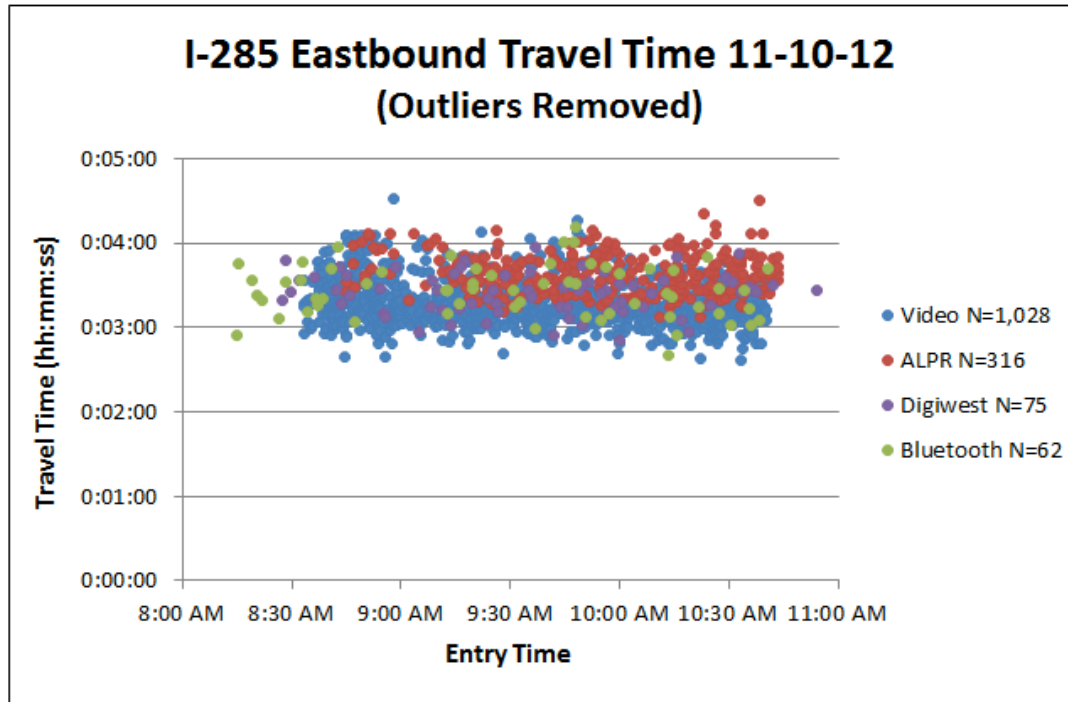


Figure 60: Video, ALPR, Digiwest Bluetooth, and Custom Bluetooth travel times from November 10<sup>th</sup>, 2012 excluding the negative travel time matches



**Figure 61: Video, ALPR, Digiwest Bluetooth, and Custom Bluetooth travel times from November 10<sup>th</sup>, 2012 excluding the negative travel time matches and outliers**

From the travel time plot in Figure 61, it can be seen that the corridor experienced free-flow conditions throughout the deployment time period with travel times averaging around three to four minutes. Even though this corridor experienced free-flow conditions throughout the deployment, the travel time plot shows that the ALPR and both types of Bluetooth devices produced slightly slower travel times than those produced by the license plate video processing as was also the case with the October 20<sup>th</sup> work zone deployment. Additionally, the plot also suggests that, for this deployment, the ALPR units were more biased toward slower moving vehicles than either of the Bluetooth units was. This is congruent with the previously discussed theory that the ALPR cameras are biased towards detecting slower moving vehicles due to occlusion and distance limitations and that the Bluetooth units are biased towards slower moving vehicles

because they are in the detection zone for longer lengths of time. Since the corridor was not congested during this deployment, the ALPR occlusion limitation should have been reduced but the distance limitation could have still prevented the ALPR cameras from picking up the faster moving vehicles in the inside lanes. Furthermore, because the corridor was experiencing free-flow conditions, the speed differential between the vehicles in the inside lanes and the vehicles in the outside lanes may not have been large enough to produce a significant difference in the amount of time the two sets of vehicles were in the detection zone to produce a bias in the Bluetooth data.

The y-y plots comparing each pair of the four technologies deployed in this data collection effort are presented in Figure 62 below. These y-y plots were again created by plotting the average travel times produced by the technologies over five minute bin periods. These y-y plots do not show the best fit linear regression lines and their associated r-square values because this deployment also only involved one congestion level. The y-y plots confirm that the ALPR travel times were, on average, slower than the video license plate processing travel times. The Digiwest and custom Bluetooth travel times were also on average slower than the video license plate processing travel times, but not as significantly as the ALPR travel times. The video processing travel times may again be slightly biased towards faster travel times due to differences in the license plate data entries across the different freeway lanes. Finally, the two y-y plots comparing the ALPR travel times to each of the Bluetooth travel times show that the ALPR travel times were slower and the y-y plot comparing the two Bluetooth travel times shows that they were overall comparable.

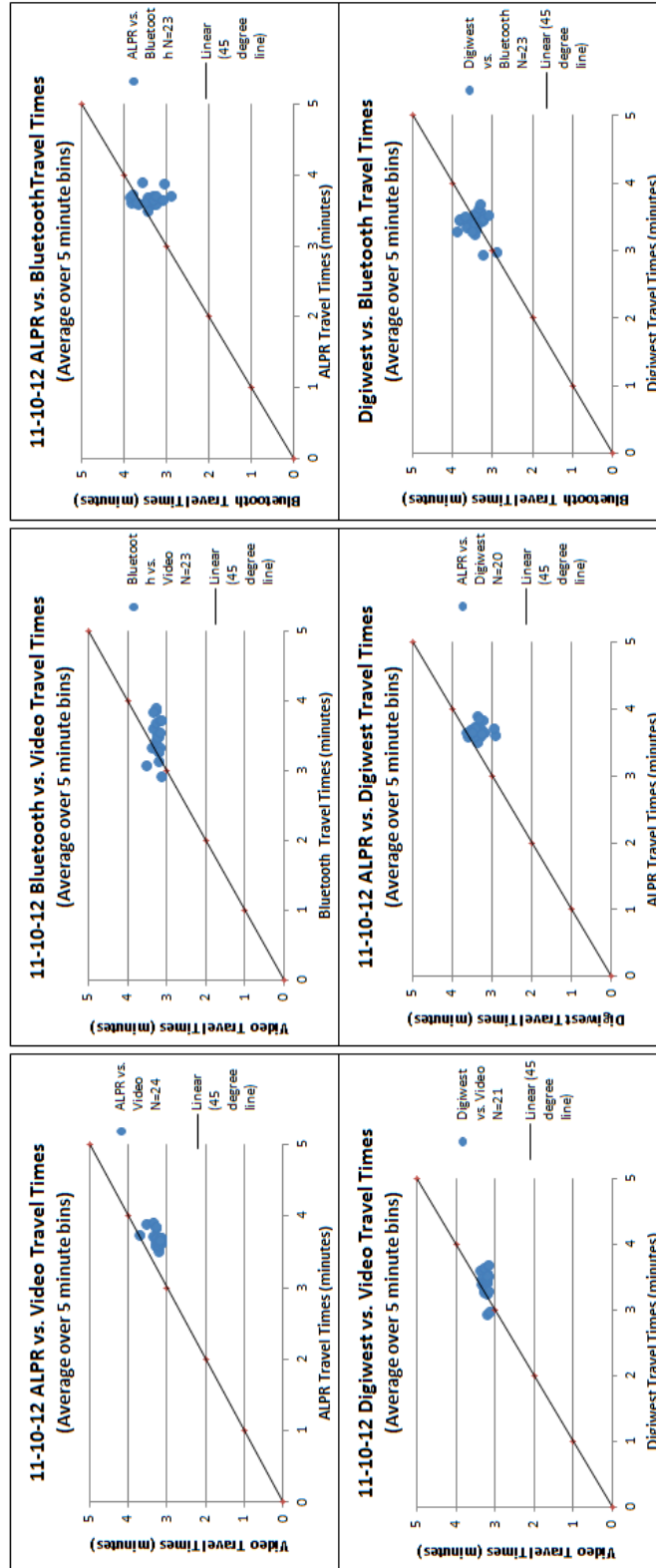


Figure 62: Comparison y-y plots for technologies deployed on November 10<sup>th</sup>, 2012

### 5.2.3 Lane Bias Analysis Results

As was previously mentioned, a lane bias analysis was conducted on the October 20<sup>th</sup>, 2012 deployment data to investigate travel time differentials across freeway lanes and if a bias may be introduced into the travel times produced by the various technologies if they detect different percentages of vehicles travelling in each of the freeway lanes.

Table 3 below shows the breakdown by lane at Site A (Paces Ferry Road) for the video and ALPR travel time matches from the October 20<sup>th</sup> deployment. (The method used to determine the lane that the ALPR travel time matches were in at Site A was previously described in section 4.2.9 of this thesis). The second through fifth columns in the table show, for each freeway lane, the number of vehicles that passed each site, the number of travel time matches that were made between these vehicles using the video processing license plate data, and the average travel time for these travel time matches. The sixth through ninth columns in the table show the total number of unique ALPR license plate detections at each site and, for each lane, the number of ALPR travel time matches, and the average travel time for these travel time matches.

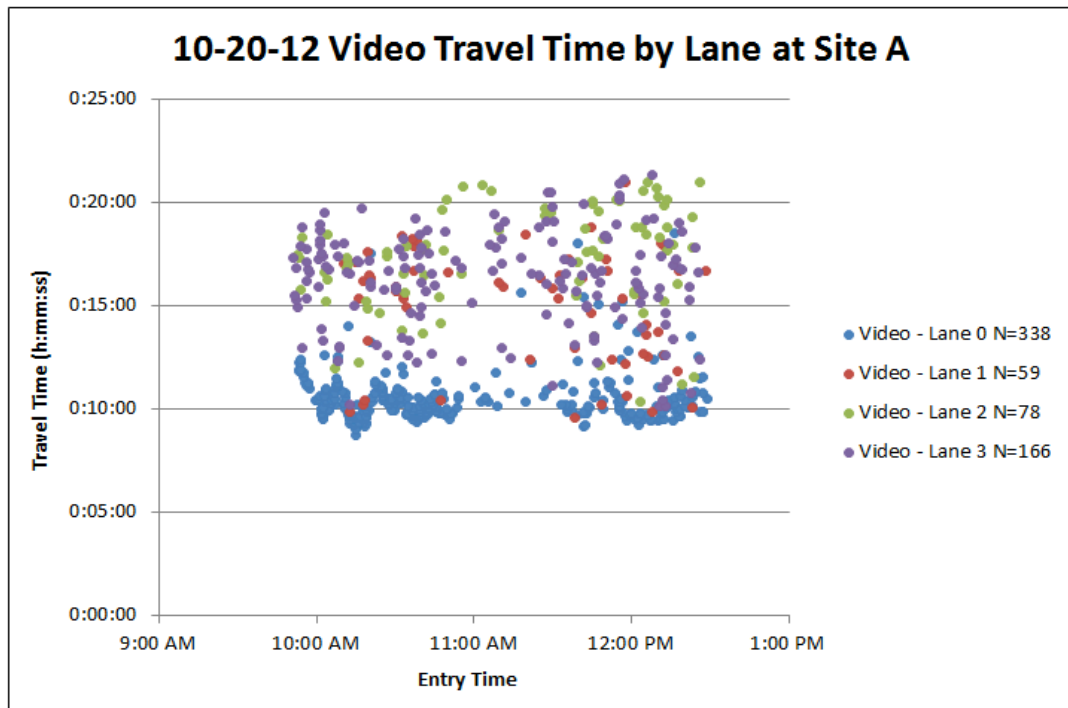
**Table 3: Lane breakdown for the video and ALPR travel times from the October 20<sup>th</sup>, 2012 deployment**

Saturday, October 20 <sup>th</sup> , 2012 (Active Work Zone)	Lane at Site A	Total Vehicle Volume at Site A	Total Vehicle Volume at Site B	# of Video Matches (by lane at site A)	Avg. Video Travel Time (by lane at site A)	# of Unique ALPR Detections (Site A)	# of Unique ALPR Detections (Site B)	# of Corrected ALPR Matches (by Lane at site A)	Avg. ALPR Travel Time (by lane at site A)
	Lane 0	2,260	559	338	10:29	unknown	unknown	2	17:08
	Lane 1	791	928	59	14:56	unknown	unknown	6	18:04
	Lane 2	802	1,814	78	17:15	unknown	unknown	48	19:19
	Lane 3	1,243	1,574	166	16:14	unknown	unknown	152	17:43
	Lane 4	N/A	948	N/A	N/A	N/A	unknown	N/A	N/A
	<b>Total</b>	<b>5,096</b>	<b>5,823</b>	<b>641</b>	<b>N/A</b>	<b>3,157</b>	<b>1,663</b>	<b>208</b>	<b>N/A</b>

The average video travel time column of the table shows distinct travel time differences for vehicles identified in each of the four freeway lanes at Site A. The fastest travel times were experienced by the vehicles in lanes zero and one at Site A with the next fastest travel times experienced by the vehicles in lane four and the slowest travel times experienced by the vehicles in lane three. These results show that there are distinct travel time differences across the various freeway lanes. Furthermore, Figure 63 below shows a travel time plot of each of the travel time matches from the video license plate processing color coded by lane number at Site A. On the average, this travel time plot shows faster travel times experienced by vehicles travelling in the left lanes as compared with vehicles travelling in the right lanes.

For the ALPR lane bias analysis, the total number of unique ALPR detections for each lane at each of the sites is unknown because not all of the ALPR detections were able to be matched with their corresponding lane number. However, the average ALPR travel times for vehicles in each of the four lanes at Site A were calculated using the 208 ALPR travel time matches that were able to be assigned to their lane at Site A. These average ALPR travel times do not show as much of a difference across freeway lanes as the average video travel times and tend to be higher. One possible explanation for this is that the vehicles that were detected by the ALPR cameras at Site A from the inside lanes are likely to have been detected in one of the outside freeway lanes at Site B. The reasoning for this is that only a small percentage of the vehicles travelling in the inside lanes are detected by the ALPR cameras due to occlusion and sight distance limitations, so it is very unlikely that these eight ALPR matches from lane zero and lane one were detected in the inside lanes at both sites A and B. Because the ALPR matches from the

inside lanes at Site A were likely in the outside lanes at Site B, they spent more time in the slower moving outside lanes than if they had maintained the inside lanes for a larger portion of their trip from Site A to Site B so their resulting travel times are slower. Additionally, some differences between the travel times produced by the video matches and the ALPR matches may be attributed to these two sets of travel times are not being measured between the exact same two points in the freeway (the ALPR units were set up in advance of the interchange overpasses and the video cameras were aimed beyond the interchange overpasses).



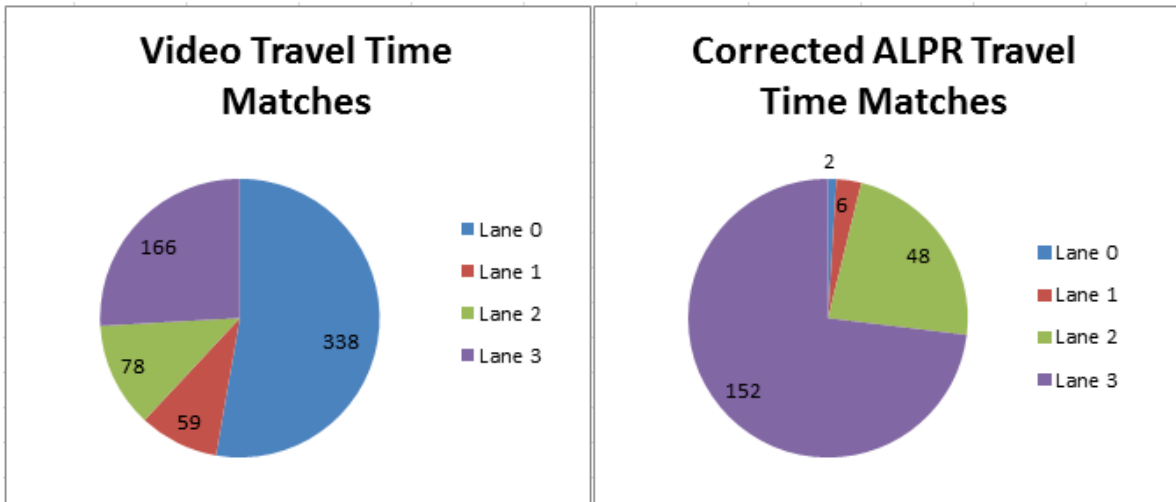
**Figure 63: Travel lane breakdown of the travel time matches from the video data for the October 20<sup>th</sup>, 2012 deployment**

The more striking takeaway from the lane bias analysis is that the greatest percentage of the video travel time matches were from lane zero and the greatest



percentage of ALPR travel time matches were from lane three. Pie charts showing the percentages of travel time matches from each lane for the video and the ALPR data are shown in Figure 64 below. The video cameras are biased towards producing travel time matches between vehicles in the inside freeway lanes for several reasons such as there are fewer tractor trailer trucks in the inside lanes so less license plate occlusion occurs and the vehicles travelling in the inside lanes may be less likely to be exiting the freeway within the corridor so a higher percentage of these vehicles may travel through the entire deployment corridor. As was previously discussed in the travel time results section, there are also several reasons why the ALPR cameras would be biased towards producing travel time matches for the vehicles travelling in the outside freeway lanes such as being restricted to these outside lanes due to occlusion and camera sight distance limitations. The occlusion limitation was particularly present during the October 20<sup>th</sup> deployment because the Paces Ferry Road (Site A) ALPR set-up location experienced bumper-to-bumper congestion conditions throughout the majority of the deployment.

The implication of this lane bias analysis is that travel time differentials across the freeway travel lanes exist, which means that where the various technologies are biased towards specific freeway lanes introduces significant bias into their travel time results that becomes more pronounced as congestion worsens.



**Figure 64: Comparison of the travel lane breakdowns for the ALPR and the video travel time matches from the October 20<sup>th</sup>, 2012 deployment**

## CHAPTER 6

### CONCLUSIONS

#### *6.1 Summary of Results*

##### **6.1.1 Detection Rate and Accuracy Summary**

In summary, the results of the Spring Street camera angle configuration test showed that the 25mm ALPR camera is best suited for capturing vehicles in the closest lanes, the 35mm camera is best suited for capturing vehicles in the middle lanes, and the 50mm camera is best suited for capturing vehicles in the far lanes, but that there is also some overlap between the lanes for which each camera is able to capture vehicles. The Spring Street camera angle configuration test also showed that the camera angle has a significant impact on both the detection and accuracy capabilities of the ALPR system. When the correct camera and angle pairings were used, the ALPR system was able to detect around 80-90 percent of passing vehicles and was able to detect and correctly read between 50-75 percent of the passing vehicles.

The I-285 freeway results showed that the ALPR system was able to detect between 20-60 percent of passing vehicles. Limitations such as the increased distance that the cameras were set from the edge of the roadway, the increased roadway width, and the increased chances of vehicle occlusion yielded lower detection rates for the I-285 freeway deployments compared to the earlier Spring Street deployment. Also, the wide range in detection rates from the I-285 freeway deployments shows that slight differences in the ALPR system set-up can have substantial impacts on system performance.

### **6.1.2 Travel Time Summary**

A major takeaway from the travel time results from the I-285 deployments is that multiple travel time bands can develop in a corridor that is experiencing heavily congested conditions due to distinct travel time differences across individual freeway lanes. These travel time differentials can develop because vehicles typically travel faster in the left lanes of a freeway but, more importantly, can also develop due to increased back-ups occurring in some lanes due to vehicles merging at work zone lane closure locations or perhaps even from the operation of heavy equipment within the work zone. In both of the work zone deployments discussed in this thesis, the lane closures were for the inside left lane(s) of the freeway, which was purposely chosen so that the ALPR units could be deployed from the outside shoulder and still capture vehicles in the closest freeway lanes. It would be interesting to investigate what types of travel time differentials may develop in work zones where the lane closures are in the right side/outside lanes of the freeway.

Another major takeaway from the travel time results is that the ALPR system appears to be biased towards the travel times of the lanes adjacent to the ALPR system placement. During the October 20<sup>th</sup> deployment, the ALPR systems were set up adjacent to the slower moving lanes and therefore the travel time results were biased towards the slower moving vehicles. If the ALPR units had instead been placed inside construction barrels located near the median of the freeway, the ALPR units would likely predict travel times biased towards the faster moving vehicles. When planning for a deployment of the ALPR systems in an active work zone, the lane closures and the resulting travel

time differentials should be considered when deciding the best set up locations for the ALPR systems.

### **6.1.3 Lane Bias Summary**

The results from the I-285 freeway deployments show that the ALPR and Bluetooth devices tend to be biased towards slower moving vehicles and therefore produce average travel times that may be slower than the actual average travel times. The ALPR devices may also be capable of producing travel times that are biased towards the faster moving vehicles if they are set up adjacent to the faster moving lanes. The video license plate data was collected with the intention of providing comparison travel time data, but the results from the lane bias analysis show that the video license plate travel times may also have a bias towards the faster moving lanes (due to license plate occlusion in the more congested lanes) and therefore may produce average travel times that are faster than the actual average travel times.

The combination of the existence of travel time differentials across freeway lanes plus the bias of the vehicle detection technologies towards specific lanes of the freeway results in noticeable travel time biases that increase as congestion increases. It may not be a significant drawback for the ALPR or Bluetooth technologies to produce travel times that are slower than the actual average travel times in a corridor because motorists are less likely to become upset by having been told they would experience a slower travel time as the likely would if they had been told they would experience a faster travel time. However, a problem could arise if the ALPR devices are set up adjacent to the fast moving travel lanes, as motorists are more likely to become upset if they experience slower travel times than they were communicated. It will be important to take this into

consideration when deciding where to place the ALPR units in an active work zone corridor.

## *6.2 Research Limitations*

### **6.2.1 Site Restrictions**

A limitation on the six I-285 freeway deployments was the numerous restrictions on site selection. As was previously discussed, deployments were restricted to sites that could be easily accessed from nearby parking lots on foot, had traversable roadside areas, had guardrails or concrete walls, had relatively flat surfaces, had freeway overpasses with sidewalks, as well as other restrictions imposed by the Bluetooth equipment. The flexibility of similar deployments in the future may be significantly increased if the research team is able to obtain access to deployment locations that are not directly accessible by foot. Additionally, if the ALPR units were deployed by a contractor or vendor as part of an active project, many of these site restrictions would not apply.

### **6.2.2 Construction Schedule**

Uncertainty in the construction location until one or two days prior, and possibly less, to the deployment limited the ability to plan the data collection. To be effective, any work zone data collection system will need to be capable of being deployed quickly with little pre-planning required.

### **6.2.3 Equipment Transport and Set-up Time**

Another limitation to the I-285 freeway deployments was the extensive time required to transport and set up the ALPR systems. The ALPR system consisting of the

three cameras, processing unit, large gel cell battery, and connection cables were transported to the sites in a large Pelican box with wheels along with the three ALPR tripods and the netbook computer. The Pelican box was cumbersome due to its size and was heavy due to the large gel cell battery. It took a significant amount of time and effort to transport the ALPR equipment from the parking lots to the data collection sites by foot. Once the ALPR equipment was at the data collection site it also took a significant amount of time to set the system up mostly due to the time required to position the ALPR cameras at the correct heights and angles. If the ALPR systems were deployed in large-scale deployments these limitations could be removed by transporting the equipment directly to the site using a vehicle and by pre-packaging the equipment in a manner that reduces the time required to correctly position the cameras.

#### **6.2.4 Data Processing Time**

The results presented in this thesis were also limited by the time required to post-process the data that was collected during the deployments. The most time consuming data processing effort was the license plate video processing. Substantial time was also required to QA/QC the ALPR data and to establish the corrected ALPR license plate numbers. Future efforts to automate much of this process should aid in reducing processing time.

### *6.3 Large-scale Work Zone Feasibility*

#### **6.3.1 Orange Barrel Installation**

One possible solution for making the ALPR system more portable and easier to set-up would be to install the system inside of orange construction barrels. One ALPR

camera could be mounted inside each construction barrel at a pre-set angle and a marking could be placed on the top of the barrel to indicate the direction that the barrel should be placed relative to the roadway. The processing unit and netbook computer could be placed inside of a separate orange barrel and could be connected to the cameras using breakaway connections so that the processing unit would not get damaged if a vehicle were to hit one of the camera barrels. This alternative set-up method would make the ALPR system more feasible to deploy in a large-scale real world work zone environment.

### **6.3.2 Battery Power**

Another possible solution for making the ALPR system more portable would be to implement an alternative power source to the use of the large gel cell batteries. The gel cell batteries are heavy and it would be difficult to place them inside of an orange construction barrel in a freeway work zone environment. It could also potentially be difficult to switch the batteries in and out of the construction barrel when they need to be recharged. Because they were designed to be used in police vehicles, the ELSAG ALPR systems are designed to run off of the power from a running vehicle. This opens the possibility for the ALPR system to run off of the power from a nearby truck or other construction vehicle as long as it could be parked near the system deployment location without interfering with the construction activities.

## *6.4 Further Research*

### **6.4.1 Real-Time Travel Time Applications**

Further research could focus on establishing a platform to transmit and communicate the ALPR travel time data in real-time. One of the goals of the work zone



testbed project is to investigate the capabilities of the technologies to transmit their travel time data in real-time. Both the Digiwest Bluetooth and the iCone units came with the capability of communicating their travel time data in real-time, however, the ELSAG ALPR system did not as travel time data collection is not the intended purpose for their equipment. A research group at Georgia Tech has already begun this research and is currently developing a platform to communicate the ALPR travel times in real-time.

#### **6.4.2 ALPR Freeway Lane Identification**

A major limitation for the analyses conducted in this thesis was that it was very difficult to identify the freeway lane for each of the ALPR license plate detection. An alternate method to determine these freeway lane numbers may be to use the pixel size information from the ALPR license plate images. This method may work if distinct differences in pixel sizes exist for each of the four to five travel lanes for each of the three ALPR camera focal lengths. Having freeway lane determinations for all of the ALPR license plate reads would add robustness to the ALPR detection and accuracy rate analyses.

#### **6.4.3 ALPR Detection and Accuracy Rates**

Future research related to this thesis could focus on determining the ALPR detection and accuracy rates from the series of I-285 deployments. The corrected ALPR license plate reads for the September 7<sup>th</sup>, October 20<sup>th</sup>, and November 10<sup>th</sup> I-285 freeway deployments have already been established. Common errors in the ALPR license plate reads could be identified and programming scripts could be developed to investigate how often these errors occur in the ALPR license plate reads. Differences in the detection and

accuracy rates related to the four different ALPR camera angles tested during the six I-285 deployments could also be investigated. If the freeway lane numbers can be established for a large portion of the ALPR license plate reads, the detection and accuracy rates could also be investigated on a lane-by-lane basis. Additionally, differences in detection and accuracy rates could be investigated for in-state vs. out-of-state license plates, new vs. old Georgia license plates, vanity vs. standard vs. specialized license plates, and tractor trailer truck license plates vs. other license plates.

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